REPORT TO THE

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COST-REDUCING METHODS FOR INSTALLING RESIDENTIAL GROUND-SOURCE HEAT PUMPS

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Ground source heat pumps represent an energy efficient technology that provides an effective method to heat and cool buildings. The commercialization of this technology has been slow and reflects the high installation costs of the ground loop.

Recognizing this barrier, the Ministry of Energy jointly with Ontario Hydro, commissioned a study to assess various drilling and installation techniques associated with ground source heat pumps.

I think you will find this report, "Cost Reducing Methods for Installing Ground Source Heat Pumps" beneficial in overcoming information barriers to the implementation of ground source heat pump systems.

Vincent G. Kerrio
Minister of Energy

In order to encourage the adoption of heat pump technology in Ontario, the Ministry of Energy commissioned a study on the Cost Reduction Potential of new Ground-Source Technologies.

The Ministry of Energy does not warrant the accuracy of data in this report.

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SUMMARY

Ground-source heat pumps can provide customers in Ontario with space- and water-heating energy at as little as one-third the cost of conventional energy sources and with about half the peak electric demand of other electric heating systems. However, the high installed cost of current ground-source systems limits their attractiveness at present energy and interest rates. Typical ground-source heat pump systems deliver between 10 and 15 kW of heat and cost between 8 and 12 thousand dollars to install. This report partitions the costs of a typical system into hardware and installation components and concludes that the buried-pipe ground-coil accounts for half the system price. Costs for this aspect of the ground-source system are high because of the "newness" and uncertainties of the job faced by the installing contractors.

Many competing drilling methods adapted from other applications are being used for ground-source heat pump installation. This study evaluates almost all available methods and concludes that although no single drilling machine is best for all parts of Ontario, there are major savings to be had by selecting the proper rig for the local conditions. This study did not discover a drill rig that combined high installation economy with the capability to drill in all subsurface conditions, as was initially anticipated. Different rigs are more productive in certain subsurface conditions than in others. Installation economy is best achieved by selecting the drilling rig best suited for the geology at the customer's site. To aid in dispelling some of the uncertainties in this task, a set of maps and an accompanying selection procedure is given. Favorable soil conditions and the right drilling method can result in a cost reduction up to 1/2 of the drilling cost, or about 1/4 of the $10,000 typical total system cost.

This report also examines the cost reduction potential of new ground-source technologies, including changes in the design and sizing of present heat pump equipment. Although some design changes may increase the economic attractiveness of ground-source systems, further research is needed to quantify these benefits. The greatest short-term potential for reducing system costs from a hardware standpoint is through a reduction in system size. Another 1/4 of the typical system cost could potentially be saved in this manner, but the resulting heating system would have higher peak electric demands. At present, few utilities have rate structures which reflect the societal benefits of such peak reductions, and without this recognition, customers may well opt for this short-term saving.

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1 INTRODUCTION

Methods for reducing the cost of closed-loop ground-coupled heat pump systems were studied by Ontario Hydro under the sponsorship of the Ontario Ministry of Energy. Ground-coupled heat pump systems are currently marketed, but the significant operating cost savings are often outweighed by high installation costs. Typical installed costs range between 8 and 12 thousand dollars for systems sized to deliver between 10 and 15 kW of heating power. The heat exchanger in the ground was singled out for concentrated study because it represents a high proportion of the cost. The most common residential systems require 250 m to 380 m of buried pipe to act as the heat exchanger between the heat pump and the earth. In the following sections, the present hardware and installation methods are reviewed, with a comparison between the horizontal and vertical types of closed-loop system. A discussion of the various drilling methods now in use is followed by recommendations that could lead to a streamlining of installation procedures and a reduction of installation costs.

Ground-source heat pumps (GSHPs) are machines that remove heat from the ground or ground-water to provide heat at temperatures suitable for space heating and/or hot water heating. If heat is taken from well-water, the terms "well-water heat pump" or "ground-water heat pump" are often used. For these systems, the well-water is pumped to a heat exchanger where it is chilled several degrees by the heat pump's refrigerant before being discharged to a stream, pond, or second well. If the heat is taken directly from the soil, the terms "ground-coupled heat pump" or "closed-loop heat pump" are often used. For the closed-loop ground-coupled systems, tough plastic pipe is buried either horizontally or vertically in soil. These pipes are filled with an antifreeze solution which is circulated to the heat pump's refrigeration system. The antifreeze is chilled several degrees, by the heat pump, and returned to the buried pipe colder than the surrounding soil. This allows the

antifreeze to absorb heat from the ground.

Heat absorbed from the antifreeze by the heat pump's refrigerant is then raised to space heating temperatures by the mechanical work of the compressor. The principal advantage of a GSHP is that 2.5 to 3.0 times more energy is delivered to the heated space than is consumed by the electrically-driven compressor and associated equipment. This means that compared to conventional electric resistance heating, energy costs can be reduced by up to 65% (1).

A second advantage of a GSHP system is the lower peak power demand during cold periods, coincident with heavy electric consumption (2). This electric demand reduction stems from the stable ground-temperatures that give the GSHP a near constant coefficient of performance (COP) over the whole winter. Compared to conventional electric resistance heat, peak power demand is 50% less.

Other advantages available with most GSHPs are lower-cost hot water heating and summer air-conditioning. These features are provided by GSHPs with desuperheaters and reversing valves, respectively. When both a desuperheater and a reversing valve are used, summer air-conditioning is accompanied by the production of virtually free hot water during the times when space cooling is required.

2 PRESENT STATUS

2.1 COST COMPONENTS

Ground-source heat pumps of the vertical closed-loop type are presently being installed in urban areas for between $8,000 and $12,000. Deviations from this price range will occur based on the size of the equipment, the features incorporated (i.e. hot water heating) and the geology of the site. The price can be broken down between two major sub-systems; the heat pump unit itself, and the buried ground-coil. Additional charges are made for any ductwork, wiring, and backup heating needed to complete the particular installation. Typical costs associated with each item are shown below for a 4-ton heat pump installed in Toronto.

Table 1

TYPICAL COST BREAKDOWN FOR A 4-TON HEAT PUMP

Item	Cost
Vertical Ground-Coil	$4,500
4-Ton Heat Pump	$4,000
Ductwork	$ 500
Backup Heating Package	$ 500
Wiring	$ 500
Total (approximately)	$10,000

The two most costly items, the ground coil and the heat pump itself, are discussed in the next section.

2.2 GROUND COIL

Approximately one half ($4,500) of the total installed cost for a 4-ton system is associated with the ground-coil piping. Of this one half, about one third ($1,500) pays for the materials and labour to insert and connect the piping. It is assumed that about 370 m (1200 ft) of pipe will cost $600 and couplings and labour will make up the rest. The remaining $3,000 must cover the drilled vertical holes (assume 185 m (600 ft) of hole costing $16/m ($5/ft)). Horizontal configurations needing only a series of trenches in which to bury the pipe cost about $1000 to $2000 less.

Vertical Systems - Drilling Costs

In urban areas, vertical drilling is extensively used because of space constraints. Drilling costs for these types of systems can vary a great deal because of the variations in soil structure across Ontario. In the Toronto area, drilling costs around $16/m ($5/ft) are not uncommon for vertical drilling.

As will be discussed in Section 4, the two most common vertical drilling methods now being used are augering and rotary drilling. Augers are generally used in dry or sandy soils for depths less than 30 m, while rotary rigs tend to be more suitable for holes between 40 m and 60 m and are not limited by the local geology.

In southwestern Ontario (specifically between London and Windsor), augers are used exclusively because of the soft clay soils. This normally makes the drilling cost 30% to 40% less than for the Toronto area. In the Windsor area, costs as low as $4.10/m have been reported for a novel wet auger rig. This wet auger rig has also been tried in the Toronto area with similar success at about the same price in certain soil conditions.

Vertical Systems - Configurations

The most common configuration for vertical systems is 3.8 cm ID (1.5") plastic pipe inserted into several (4 to 8) holes, depending on the depth. The hole diameter normally drilled is 15 cm (6"). These pipes are assembled with a U-bend at the bottom and are inserted down the drilled holes. Pipes from each hole are then connected in series (see Appendix A, figure A2). The total buried pipe length is a function of the heat pump output capacity (equipment rating) at 10°C. For vertical systems, 26 m of pipe per kW of output (300 ft/ton) is a rule-of-thumb used to determine the required pipe length. Of course, the drilled hole length required is half the pipe length because of the U-tube in each hole. Another pipe size and hole size that is tried for moderately-sized series-connected systems (under 14 kW output) is 3.2 cm (1.25") pipe with a 13 cm (5") hole diameter.

As an alternative to the series connection method, smaller diameter (2.5 cm (1") ID) pipes are sometimes used to reduce the hole diameter to 10 cm (4"). The pipes from these smaller diameter holes are then connected in parallel to obtain the similar flow and pressure drop conditions. These and other vertical configurations are schematically shown and discussed in Appendix A.

Horizontal Systems

In rural areas, the availability of land makes it possible to use a horizontal ground-coil system for GSHP installations. This generally drops the installed cost by $1,000 or more, depending on the trenching method used, because installing pipe in horizontal trenches is cheaper and easier than drilling vertical holes. In some cases, rural homeowners have the equipment (tile machines or backhoes) to carry out the ground coil installation themselves.

The most common pipe configuration for horizontal systems is one loop of 3.2 cm ID (1 1/4") plastic pipe buried between 1 m and 1.5 m (3-5 ft). A

rule-of-thumb for sizing horizontal systems is 35 m/kW output (400 ft/ton) of pipe for a one-pipe-in-a-trench system.

Other configurations involving two and four pipes in the same trench are shown in Appendix A under "Horizontal Pipe Configurations" and discussed in Section 5.2. These may have more applicability in urban areas where space is a constraint.

2.3 EQUIPMENT

Sizing

Heat pump costs go up with their capacity rating, which in turn is directly related to the size of the compressor. The most popular air-to-air heat pumps (and central air-conditioners) have capacities between 2 and 3 "tons", (7 to 11 kW output) corresponding to compressor ratings of 2 to 3 horsepower (1.5 to 2.2 kW mech). These heat pumps are normally found in this range because the units are sized for air-conditioning duty. Backup heating is required during cold weather because an air-source heat pump's output drops with outdoor temperature and it would not be economical to size such a heat pump to the design heat loss. On the other hand, GSHPs have a virtually constant output at all outdoor conditions and can be sized more closely to the design heat loss. This means the units are normally sold in the 3 to 5 ton (3-5 hp) capacity range (11 to 18 kW output). Thus a cost difference of between $1,000 to $3,000 will tend to exist between earth- and air-source heat pumps based on the long standing empirical observation that heat pump incremental installed costs rise by about $1000 per ton of capacity ($285/kW output).

Present Costs

The heat pump itself is the most expensive component of the ground-source system. Based on an analysis of the sub-components making up the heat pump, a figure of $200 to $350/kW of output capacity ($700 to $1200/ton) was determined to fairly reflect present equipment list costs to the

dealer. The higher cost figure represents units with hot water heating sub-systems, more sophisticated control or smaller capacity machines. Installation costs are in addition to this.

Thus, an equipment cost of between $3,000 and $5,000 can be expected for heat pumps in the 9 kW - 18 kW output (2.5 to 5 ton) range. This size range is typical of the units currently being installed and is approximately 75% greater than the typical size range found for air-source heat pumps. In recognition of this significant size difference between air- and ground-source heat pumps, there has been a trend by both installers and manufacturers to reduce the unit sizes, to reduce installation and equipment costs. This tends to increase the peak electric demand expected from these units while only slightly lowering the energy savings, as more electric back-up heating is required on the coldest days. However, since no economic incentive is given to the homeowner for electrical demand savings, this appears to be a popular method of reducing installation costs.

A move towards super-insulated and R2000 homes would mean that a two-ton ground-source heat pump may be sufficient to provide heating and cooling for new energy-efficient houses. This means GSHP costs for future housing stock will be reduced to reflect smaller heat pumps while maintaining all the advantages of a system fully sized for both heating and cooling.

The costs given above are estimates based on discussions with installers and manufacturers in 1985. A total of ten GSHP companies carry out at least part of the assembly of their heat pump in Canada. Out of this total, five are located in Ontario. A list of these companies is given in Appendix B.

3 HORIZONTAL VERSUS VERTICAL SYSTEMS

Closed-loop ground-coupled heat pump systems use either vertical or horizontal buried pipe. Horizontal systems are generally cheaper to install but require more land area. Space constraints make the vertical systems the preferred method in urban areas. However, innovative work involving up to four parallel pipes in one 2.5 m (8 ft) deep trench has provided some indication that a horizontal design may work for moderately-sized urban lots (see Section 5.2).

Installation differences aside, the performance of both configurations are nearly identical for properly designed systems. Work in New York State has shown that the source temperatures of the antifreeze solution for horizontal systems are somewhat more stable in winter, partly because the pipe lengths are longer than vertical systems. However, horizontal source-temperatures were stable at slightly lower average temperatures than those of the vertical systems (3).

To size horizontal systems with a single pipe in each trench, a rule-of-thumb for the pipe length is 35 m/kW output (400 ft/ton). This is based on the equipment's output rating at 10°C. Work by Couvillion at the University of Arkansas (4) has shown that moisture movement, surface effects such as rainfall, soil types and water-table location can dramatically effect the ground-coil performance (especially for horizontal systems). These factors are particularly critical during the summer cooling season. In Ontario, however, the heating season predominates and the climate is such that, for most of the Province, the water table is high and the rainfall is sufficient to maintain conditions that are always suitable for a horizontal system. This assumes that the given location has a minimum soil depth of about 1 m and the appropriate space (approximately 600 - 900 m^2 for a 7 kW output GSHP).

Vertical systems in Ontario normally have the ground-coil in contact with ground-water. Thus, the rule-of-thumb for pipe length is about 26 m/kW output (300 ft/ton) throughout the Province.

The remainder of this report deals mainly with cost reduction methods for vertical-type systems because they have the greatest applicability in the more populated urban areas.

4 DRILLING METHODS & COSTS

4.1 INTRODUCTION

A substantial part of the investment in a ground-source heat pump is associated with the installation of the ground coil. As installation methods for ground coils are generally expensive and not well developed in Ontario, the scope for cost reduction in drilling methods was believed to be significant and this area was given special emphasis. This study concentrated on vertical ground-coil installation methods, as vertical coils are expensive compared with horizontally-placed coils and must be used in all cases where the customer does not possess sufficient land area to accommodate horizontal coils (e.g. most urban sites). Equipment and methods used for drilling holes in geologic material were examined for economy and applicability to installation of heat pump ground-coils.

4.2 SELECTION FACTORS

As described in Reference 5 there are four major factors that influence the choice of drilling equipment and drilling methods for installing ground coils. These are: geology, site constraints, environmental effects, and economic factors. Each is discussed separately below. All these factors must be considered in order to install ground coils at the least cost and in a socially responsible manner.

Geology

Geological factors are the prime determinant of the type of drilling rig and drilling method chosen. These factors include:

- the depth to bedrock
- the characteristics of the soil covering the bedrock
- the local ground-water conditions.

It has been assumed in this report that ground coils will be installed entirely in soil unless the depth of soil covering bedrock is less than 20 m. While drilling in rock is feasible, it may not be economically practical except in "weaker" rock, such as shale. Determining the depth of soil is an immediate indicator of economic viability for heat pump installation. If 20 m of soil is available, it will be easier to place multiple holes of shallower depth in the soil than to drill a few deeper holes in the bedrock.

Certain characteristics of the soil will also determine the ease or difficulty of drilling holes to accept the ground coils. High density or frequent cobbles and boulders will make drilling more difficult than in lower density or stone-free soils. Ground-water conditions in combination with soil type determine whether the hole will stand open or cave in. These factors are critical in choosing the drilling equipment, the drilling method and in planning contingency approaches to ensure successful ground-coil installation.

Site Constraints

Lot size is the prime factor in establishing whether horizontal or vertical coils should be chosen for a ground-source heat pump system. For lots that do not have the required minimum space described on page 8, a vertical system must be used. Once a vertical installation has been chosen, several factors may limit the areas on the property that may be drilled. These factors include obstacles to access and obstacles to drilling. Obstacles to access include buildings, fences, trees, landscaping (slopes) and overhead wires. The drill equipment selected must be small enough and maneuverable enough to reach and set up on the drill site. Setting up includes erecting the drill's boom. Obstacles to drilling include buried services (e.g. telephone cables, electric power cables, water pipes, sewer pipes, natural gas pipes), surface paving and underground buildings. As hitting these underground obstacles can be both expensive and dangerous, drilling locations should be carefully checked before starting to drill.

Environmental Effects

The choice of drilling equipment and drilling method can have environmental consequences ranging from local to regional. On the local scale, the size, weight and undercarriage (wheels or tracks) of the drill rig will influence the site damage caused by moving the drill. Also, on a local scale, the choice of drilling method - augering, wash boring, mud rotary, etc., - will determine the amount and condition of the drill cuttings to be removed as part of site clean-up. On a regional scale, drilling method is important in controlling artesian ground-water conditions and sealing of the hole is important in preventing contamination of ground-water drinking supplies. Negligence in these latter areas may lead to expensive legal action.

Economic Factors

While the choice of drill equipment and method will be limited by geologic, site and environmental factors, the opportunity to make a final selection based on economics will still be available in many instances. In some cases a tradeoff decision between risk and cost may also be required. The risk/cost decision may involve (a) choosing between a less costly drilling approach that has marginal capability to complete the work on a site and a more costly drilling approach that has "guaranteed" capability to complete the work, or (b) choosing between fixed-price and time-plus-materials drilling contractors.

Drilling costs will be affected by the drill size, method flexibility and proximity of the drilling equipment to the customer's site. The experience and productivity of the drill crew will also be an important factor. In general, drill equipment becomes more expensive as it becomes larger and/or has increased capability to use several drilling methods. Mobilization costs are directly proportional to the distance the drill has to travel to the site. Costs should be lowered with highly productive crews.

4.3 DRILLING METHODS AND EQUIPMENT

Drilling is in essence a means of cutting through subsurface materials and removing the cuttings from the hole. Some drilling methods also have the ability to maintain an open hole in difficult ground-water or caving subsurface conditions.

Methods

Drilling methods can be classified as: 1) augering, 2) conventional rotary (wash boring), 3) mud rotary, 4) air rotary, 5) percussion, 6) sonic, or 7) water jetting. The first three methods are most commonly used for heat pump installations.

Augering cuts the soil into large pieces which are mechanically transported to the top of the hole by rotating the continuous flight augers and moving them up and down in the hole using the drill. Augering is normally done "dry" (i.e. no fluids are introduced into the hole). Either solid-stem or hollow-stem augers may be used in dry augering. Solid-stem augers must be removed from the hole prior to installing ground coils. Hollow-stem augers, illustrated in Figure 1, allow the coils to be placed in the ground, through their hollow center, prior to removing the augers from the subsoil. Augering can also be done "wet" by forcing a fluid (normally water) down a small hollow in the center stem of the augers. The fluid flows back up the hole outside the augers, helping to transport the cuttings to the surface and to keep the hole open when the augers are withdrawn. As wet auger equipment does not recirculate the drill fluid, the fluid is wasted on the drill site. The speed of auger drilling depends to a large extent on the torque and downpressure that the drill can apply to the augers.

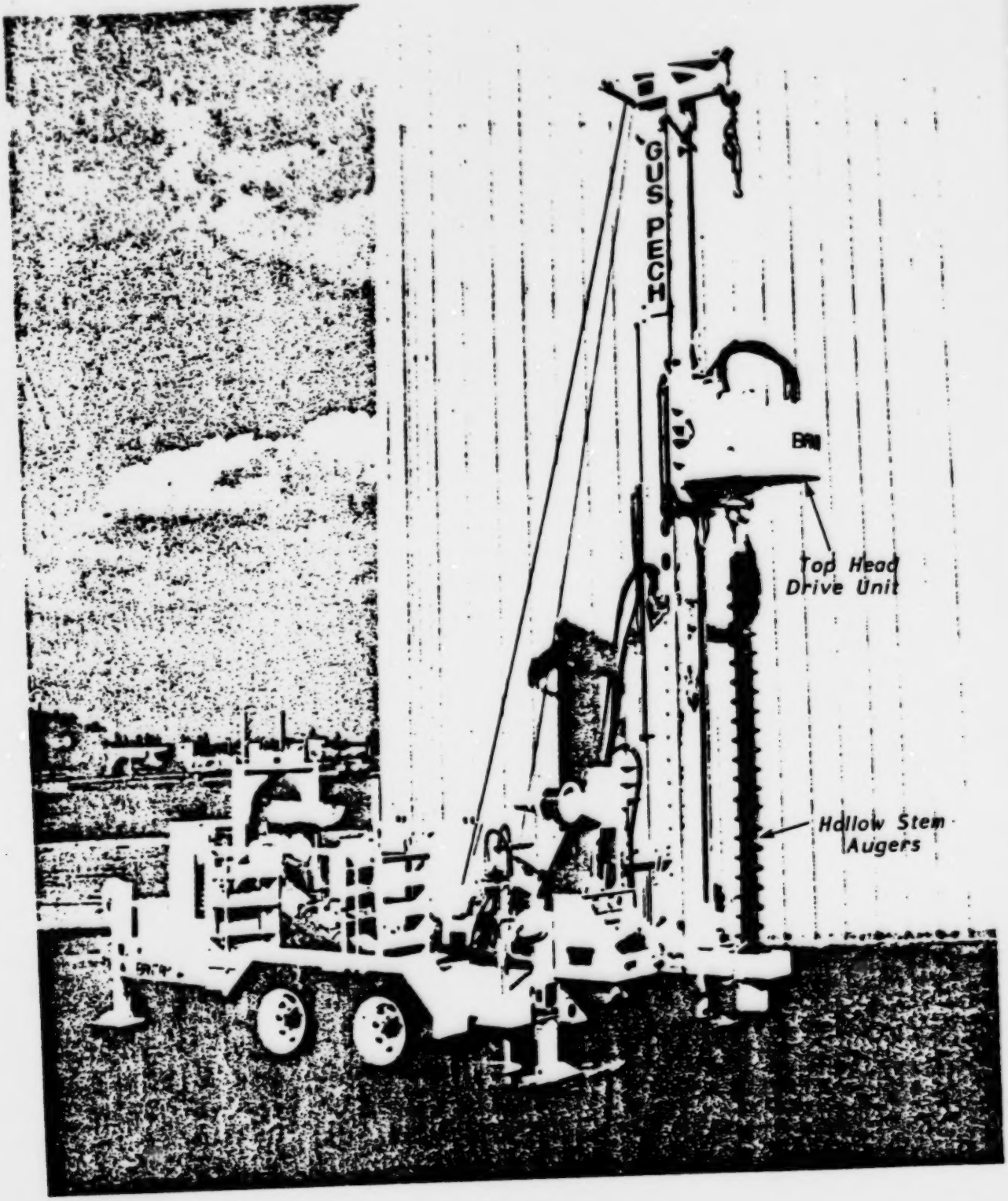

FIGURE 1

DRILL RIG EQUIPPED WITH HOLLOW STEM AUGERS (COURTESY GUS PECH BROCHURE)

In conventional rotary, mud-rotary, and air-rotary drilling, the subsurface material is ground into small fragments by a cutting tool and flushed out of the hole by the drill fluid (water, mud or air). The cutting tool normally used is a tricone bit (illustrated in Figure 2). A carbide-button bit, as shown in Figure 3, may be used in air-rotary work where percussion action assists the rotary action in cutting the subsurface material. Coring tools impregnated with industrial diamonds (see Figure 4) are also used in certain soil and most rock sampling operations. The fluid used in rotary drilling is forced down the center of the drill rods, through the drill bit and back up the hole. Besides removing cuttings the wet fluids also lubricate and cool the drill bit and hold the hole open. Normally, the drill fluid is recirculated in rotary drilling, using a steel tank or a pit excavated in the ground as reservoir and trap for the cuttings. Mud rotary is frequently the only workable method for drilling in artesian or caving ground-conditions. The speed of rotary drilling depends on the speed at which the cutting tool is rotated and the downpressure applied to the tool through the drill rods.

Percussion drilling employs a rapid up-and-down motion to chop the subsurface material into pieces which are flushed out of the hole by high pressure air. The percussion hammer may be located above ground, acting on the drill rods, or may be located down-the-hole, acting directly on the cutting tool. An ODEX™ bit is a special percussion tool (similar to the carbide-button bit) which is used to install casings in soil while the hole is being drilled.

Sonic drilling is percussion drilling performed at a higher impact frequency. The drill bit is vibrated at high frequency but small amplitude. Again, cuttings are removed by high-pressure air. This method is still in the developmental stage.

FIGURE 2

TRICONE BIT
(COURTESY J.K. SMIT BROCHURE)

FIGURE 3

CARBIDE BUTTON BIT
(COURTESY J.K. SMIT BROCHURE)

FIGURE 4

DIAMOND CORING BIT
(COURTESY J.K. SMIT BROCHURE)

Water jetting resembles conventional-rotary drilling without the rotary cutting action. The hole is created by the erosive power of the water. Equipment is available which can produce extremely high-pressure water-jets capable of cutting rock and even metal. This method is not currently used in soil due to difficulties in controlling the size of the hole.

Equipment

As noted in the previous section, the drilling rate for augering is dependent on the torque and downpressure exerted by the drill rig on the augers. Downpressure capability will be limited by the weight of the drill plus its undercarriage. For a given drill rig, drilling rate and depth capability will decrease as the size of hole being augered is increased. Solid-stem augers normally produce a 10 cm hole while conventional hollow-stem augers have an internal diameter just over 10 cm and produce a hole over 15 cm diameter.

For rotary equipment, drilling rate depends on rate of rotation and downpressure. As for auger drills, the weight of the drill rig and undercarriage will limit the downpressure that can be applied. Hoisting capacity is also a limiting factor in rotary equipment. The depth of hole is limited by the weight of rods that the rig can hoist out of the hole. Hole diameters produced by the cutting tools on these drills range down to 13 cm but are commonly larger. Rotary drills are thus better suited than auger drills to install coils, which frequently measure 11 cm across the bottom U-bend.

In both augering and rotary drilling, extensions are added to the length of drilling tools in the ground as the hole increases in depth. The time required to connect the drill-string segments while advancing the hole, and to decouple them while retrieving the tools, frequently exceeds the time spent actually advancing the hole. This non-productive time can be decreased by using longer tooling segments and by using drilling rigs with longer strokes which can accommodate these tools. However,

tools longer than the 1.5 m lengths frequently used may require winches to handle their weight. This process may be slower than manual handling of the shorter segments. Drilling rigs with longer strokes may require more headroom than is available on certain sites. In caving soil conditions it is critical to get the tools out of the hole and the ground coil in the hole before collapse occurs. The length of tool segments should be selected to best balance the needs of site access, drilling speed and economy.

Vertical ground-coil installations usually require holes to be drilled at least 20 m deep and frequently 40 m deep. In order to drill to these depths economically in easy soils, the drilling rig must have this depth capability plus some reserve. A depth capability of 50 m is suggested. Additional capacity is required to drill to the same depth in difficult soils because they offer much greater resistance to drilling. A drilling rig rated for 100 m is desirable for economic drilling in difficult soil conditions even though the hole itself may not exceed half this depth.

Appendix C (Table C1) gives the values of performance factors such as torque, downpressure and depth for over seventy different rigs used in the water-well industry. In reading this Appendix it should be noted that some rigs can do both rotary and auger drilling but rigs with tophead drive capabilities (drives that apply down pressure and torque to the top of the drill string (see Figure 1)) are primarily suited to augering. Additional drill rig information, obtained during this study, is summarized in Appendix C (Table C2).

Modifications to the heat pump or ground coil which reduce the depth and/or diameter of hole required will have a positive impact on the drilling rig required. Smaller, less-expensive rigs will potentially be capable of performing the drilling work. Drilling time and cost will be reduced. Competition gained by opening the business to more drillers

and rigs may also contribute to more economic heat pump installations. It should be noted that an experienced and motivated drill crew is necessary to derive the maximum efficiency and performance from any piece of drilling equipment.

Productivity and Cost

The rate at which drilling can be accomplished depends on subsoil conditions, hole size, drill rig capability and the drill crew's capabilities. Besides experience and knowledge, the drillers' "mind set" towards drilling productivity can significantly influence drilling rates. Drilling done on a time basis rather than on a depth-accomplished basis is likely to be slower. Likewise, drillers operating in a more competitive market have more incentive to improve their productivity than drillers not challenged by competitors.

In Ontario, augering rigs are most commonly employed for subsurface engineering studies and are rented on an hourly basis. While hourly rates are competitive, productivity rates between companies and between drilling crews within a company may vary substantially. Rotary rigs are most commonly used for well drilling. Well-drilling work, which includes installing the casing, the well screen and developing the water flow, is frequently performed on a lump sum basis. It is believed that many of these rigs are not currently producing at their potential capacity. In contrast, "shot-hole" drilling for mineral and oil exploration in western Canada and the United States is priced on the drilled "length" basis. This competitive environment has produced highly productive drillers who are capable of extracting the maximum performance from their rigs. As the normal work for this equipment is not directly comparable to ground-coil installation and few rigs are currently active in the heat pump field, it is difficult to accurately gauge what productivity and pricing potential could be obtained from these rigs in a fully developed competitive situation.

To furnish some of this data for hollow-stem augering, a field trial was performed (see Appendix D). The productivity anticipated by this method was not realized during the trial.

Table 2 shows drilling rates achieved in various subsurface conditions by a variety of drill rigs and drilling methods. The human factor has not been removed from the drilling rates in this comparison so the rates are biased by the experience and competence of the rig operators. It may be seen that the highest productivity is achieved in "easy" soil conditions by large mud-rotary, wet-auger and sonic drills. Rates from 15 to 65 m/hr were reported. Most drills, even light drills, were capable of drilling in the "easy" clay or sand soils at a reasonable rate. In difficult soil conditions, the light drills are unable to perform well. Rates varying from 2 to 8 m/hr were recorded for the heavier auger, percussion and rotary rigs, with rotary rigs giving the best performance. While some rigs (rotary or percussion) can drill rock quickly, as shown in the table, their actual production is slower than indicated due to the need to first place a casing through overburden soils and to recover the casing after the installation is complete.

Costs for these drill rigs vary considerably. Ground-coil installation by wet-auger drilling is currently done for $4.10/meter ($1.25/ft). Some conventional- or mud-rotary ground-coil drilling is quoted at $16.40 to $23.00 per metre ($5-7/ft), but drillers frequently charge $32.80 to $39.40 per metre ($10-12/ft) for well installations using this same equipment. Dry auger rigs are normally rented at an hourly rate ranging from $70 to $100. Taking auger productivity into account yields a rate-per-metre similar to conventional- or mud-rotary equipment. Air-rotary, percussion and ODEX™ drilling are expected to cost in excess of $50 per metre.

Table 2

DRILLING RATES OBSERVED FOR VARIOUS TYPES OF EQUIPMENT

Drill Model	Method	Soil/Rock Type	Hole Diameter (cm)	Drilling Rate (m/hr)	Reference (see below)
Documented					
Pennadrill	auger	dense till (difficult)	13	2 - 3	1
Becker Drill	percussion	"	13	5 - 7	1
Caisson Auger	auger	"	91	2	1
CME.750	auger	sand/silt (easy)	20	4 - 5	2
Becker/EDS	percussion	dense sand (easy)	10	12	3
Atlas Copco	"	"	10	5	3
Hawker Siddeley	sonic	"	10	17	3
"	"	rock	10	4	3
"	"	sand & gravel (easy)	10	65	3
Copco Rotamec	ODEX"	overburden	15	1	4
"	percussion	rock	15	10	4
Nemec	percussion	rock	15	10	4
large well drill	rotary mud	dense till (difficult)	20	8	5
Not Documented					
CME 750	air rotary	rock (soft shale)	10	3	6
conventional	DTH hammer	boulder till (difficult)	13	8	7
well drill	mud rotary	wet sand (easy)	13	45	7
Gardner Denver	wet auger	clay (easy)	13	27 - 30	8
"	"	sands (easy)	13	15 - 27	9
"	"	rock (soft shale)	13	4	9
Perreira	conventional	sand (easy)	13	6	10
Bucyrus Erie 10R	mud rotary	rock (shale)	13	7	11
Polhydrill	conventional	sand (easy)	10	7	12
"	"	rock	10	3	12
Ditch Witch	auger (?)	sand (easy)	13	7	13
"	"	dense till (difficult)	13	<1	13
Flamingo	conventional	sand (easy)	13	7	14

1. Adams, J.I. "Grouted Anchor Test Program Pickering GS to Cherrywood TS", Ontario Hydro Research Division Report No 69-353-H, 47p, 1969.
2. Field trial November 1985 observed by C. Cragg, Ontario Hydro, (see Appendix D)
3. Armstrong, D.J. "Pencil Pile Development Program", CEA Research Project 78-76 final report, 107p, 1983.
4. Lulevarna Project News, Lulea University, Sweden, 5p, 1985.
5. Long Sault field project observed by A. Horton, Ontario Hydro, 1983.
6. Personal communication with M. Pollice, All Terrain Drilling, Waterloo.
7. Personal communication with D. Hatherton, Waterfurnace International.
8. Personal communication with P. LeBeau, R & B Drilling, Goderich. (see Appendix E)
9. Personal communication with S. Pickard, Deakin Poole, Toronto. (see Appendix E)
10. Personal communication with Perreira drill crew, Toronto.
11. Personal communication with Lunney, Lunney Well Drilling.
12. Personal communication with J. Archibald, manufacturer's representative, Toronto.
13. Personal communication with G. Di Rezze, Ground Heat Co., Toronto.
14. Personal communication with B. Wesley, Kirkland Lake.

4.4 GUIDELINES FOR DRILL SELECTION

Combining the above equipment capabilities and costs yields the information necessary in selecting the most appropriate drilling method (and hence equipment) for any particular GSHP job. Table 3 summarizes the results in a simple format. It is important to realize that the least expensive methods are applicable only to the easiest drilling jobs. The selection of a single method capable of drilling in all soils may result in higher-than-necessary costs in the easier-drilling soil-conditions.

Wet augering, the most economical and productive method, is best suited to drilling in easy-soil conditions. Conventional- or mud-rotary drilling may match the productivity of the wet auger in easy soils but not the cost. Generally, conventional- or mud-rotary are best suited to drilling in difficult soil conditions. But these methods can also be productive in rock. Higher unit prices may be charged for rock drilling than those shown in the table depending on local rock conditions. Air-rotary or percussion methods are believed to be best suited to drilling rock. To be most effective these latter methods should normally be used only when rock is at or very near the ground surface. A drilling method employing mud should be used in any flowing-well area (artesian ground-water or caving-soil conditions).

Table 3

DRILLING EQUIPMENT SELECTION

Drilling Method	Drilling Capability			Drilling Rate (m/hr)	Drilling Cost ($/m)
	Easy Soil	Difficult Soil	Shallow Rock		
Wet Augering	High	Low	Low	15-36	4.10 *
Conventional or Mud Rotary	High	High	High	6-8	16.40-23.00
Air Rotary or Percussion	Low	High	High	5-10	50.00 or more

Legend

Easy Soil: soil that is generally free of cobbles or boulders
Difficult Soil: soil contains cobbles, boulders or is very dense
Shallow Rock: depth to rock less than 20 m

* only one price, as only one driller was found using this method

To aid selection of the most efficient drilling equipment, four maps of southern Ontario have been prepared to show anticipated subsurface conditions (see Appendix F). By following the steps outlined in the decision flow-chart below, the maps can be consulted in a systematic fashion to determine the lowest-cost drilling procedure that should be successful in a given area.

1. If depth to rock is less than 20 m (see map 1):
   Then select equipment capable of drilling rock or consider horizontal ground loops.

2. If flowing well conditions are prevalent (see map 2):
   Then select equipment capable of using drilling mud.

3. If soils are classed as difficult to drill due to their high density or the presence of boulders (see map 3):
   Then select equipment capable of penetrating dense soil and boulders.

4. If the soils are classed as easy to drill (see map 3):
   Then select the most economical equipment available (probably augers).

5. If major drinking water aquifers are present (see map 4):
   Then the driller must use extreme caution to avoid ground-water contamination and uncontrolled flows.

Because of the compact size of the maps in Appendix F, small scale features cannot be shown. Local sources to consult for more detailed or site specific information are contained in the Appendix.

4.5 DRILLING SUMMARY

This study did not discover a drill rig that combined high installation economy with the capability to drill in all subsurface conditions, as was initially anticipated. Different rigs are more productive in certain subsurface conditions than in others. Installation economy is best achieved by selecting the drilling rig best suited for the geology at the customer's site.

Using present technology and installation practices, vertical loop ground-source heat pumps are most economically installed in areas of Ontario with easy soil-drilling conditions. Map 3 in Appendix F delineates these locations. Easy soil areas are logical targets for marketing emphasis. Economic installations may also be possible in difficult soil drilling areas; however, considerable scope exists to lower costs in these locations. Potential cost reductions in difficult soils may be achieved by heat pump equipment modifications that (a) reduce the borehole diameter and/or (b) reduce the depth of borehole required. Proposals to use different heat-exchange fluids and piping fall in this category and are discussed in the next two sections of this report. Modified drilling-rigs that permit rapid changes in drilling methods to meet changing subsurface conditions, say from conventional to percussion, are starting to appear on the market. Use of these rigs, adapted for heat pump installation, may aid in reducing installation costs.

While installing in rock is feasible, it may not be economically competitive (with the possible exception of shale areas). Horizontal-coil systems are most appropriate in shallow rock areas of the Province. Innovations that reduce the depth and number of boreholes may open up more of these areas to vertical loop systems. Alternative coil arrangements, such as a spiralled coil placed in a 0.6 m to 1.0 m

diameter hole approximately 10 m deep, may also have potential in these areas. The sonic drill and water jetting have considerable potential for economic drilling of rock. These two methods are not sufficiently developed for current use, but progress should be monitored for possible future application to ground-coil installation.

5 INNOVATIVE WORK

5.1 INTRODUCTION

This section identifies concepts for ground-coil piping or the heat pump refrigerant circuit that differ enough from the commonplace systems to warrant discussion. Some of these novel concepts have just entered the marketplace as commercially available products, while others are in the developmental or research stages.

5.2 MULTIPLE PIPES IN A TRENCH

An experiment conducted in upstate New York with one and two pipes in a trench indicates the two-pipe system, buried at 0.9 m and 1.5 m respectively (3 and 5 ft), can collect twice the energy of a single pipe system buried at 1.5 m (5 ft), per unit of trench length, up to mid-March (3). After mid-March, the energy extraction rate drops to 1.6 times the single pipe design due to the thermal interference between the two pipes in the one trench. Using the worst case condition for the two-pipe design (1.6 ratio) sizing a system would then be based on 44 m/kW output (510 ft/ton) for the pipe length and 22 m/kW (255 ft/ton) for the trench length. This sizing criteria is considered valid for most of southern Ontario and could be used as a rule-of-thumb.

No clear cost advantage emerges for the two-pipe system based on the price for piping versus the price for trenching. However, in areas with limited space, this could be a viable alternative to the conventional vertical system.

Work has also been carried out on systems with four pipes in one trench (6). These systems use four pipes buried at the 2.3 m, 2 m, 1.5 m and 0.7 m levels (8, 6, 4, and 2 feet) respectively. Based on the best available data, the rule-of-thumb sizing criteria for the four-pipe system is 52 m/kW (600 ft/ton) for the pipe length and 13 m/kW (150 ft/ton) for the trench length (for Southern Ontario). This

configuration and others are presented in Appendix A under "Horizontal Pipe Configurations". The short trench length of the four-pipe system makes it an alternative to vertical drilling for urban lots of moderate size. This is especially true when shallow bedrock makes vertical systems expensive.

5.3 COPPER PIPE

A joint project carried out by Ontario Hydro and the University of Toronto in the late 1940's provides some useful design information for horizontal copper ground-coils in the Toronto area (7). This early research showed that 19.2 W/m could be collected during the most severe winter conditions experienced by the ground coil (late March). The ground coil was a 2 cm I.D. (3/4") copper-pipe system laid in trenches 1.5 m (5 ft) deep on 1.8 m (6 ft) centres. These results compare to 13.5 W/m, measured north of Toronto for plastic pipe buried 1 m (3.2 ft) deep (2). Based on the findings above, buried copper-pipe will perform 40% better than plastic pipe similarly orientated. Thus, the rule-of-thumb sizing criteria for horizontal copper is 25 m/kW (285 ft/ton) which is considerably shorter than the 35 m/kW (400 ft/ton) used with plastic.

More recent research at the National Research Council's Division of Building Research (NRC-DBR) shows that vertical copper ground-coils might have considerably better performance at temperatures somewhat below freezing and in transient situations (off-cycle periods). Tests at NRC have involved a comparison between four 1.25 cm (0.5 in) U-tube copper pipes inserted into a vertical hole 15 m (50 ft) deep and 3.75 cm (1.5 in) plastic U-tube pipe serving as a benchmark in a similar hole. The results showed that in steady-state, the four copper pipes in one hole had heat gains up to twice those of the hole with the plastic U-tube. Since this evaluation work is still in its early stages, sizing criteria, cost data, and mechanical design considerations are not yet available. NRC is also conducting research on spiral copper pipe in a 15 m (50 ft) hole 25 cm (10 in) in diameter at the same site. Results

for this system should be available in 1986. (This work is being carried out in the Ottawa area.)

5.4 REFRIGERANT-CHARGED HORIZONTAL COPPER PIPE

Circulating the heat pump refrigerant directly into a horizontal ground-coil would eliminate one heat exchanger, the antifreeze solution, and the antifreeze pump. This would allow the heat pump system to operate at colder ground coil temperatures without penalizing the system performance. However, using the refrigerant directly in the ground coil presents some refrigerant-system design difficulties in the area of oil return (for compressor lubrication) and leak detection and repair. Refrigerant-charged vertical loops have very little chance of success because of severe hydraulic head penalties and refrigerant pressure changes down and up a long vertical pipe. However, refrigerant-charged pipes in shallow holes less than 15 m deep are being used in a experiment involving five systems in Sweden. Horizontally-configured refrigerant-charged GSHPs are more common in Sweden and number in the thousands.

Work by Svec, Goodrich, and Palmer at NRC indicates that copper pipe has significant performance advantages over plastic pipe both in steady-state and in transient conditions, at temperatures several degrees below freezing (8). Heat extraction rates as high as 30 W/m and 40 W/m may be possible in steady-state for a copper ground-coil operating several degrees below zero. Thus, the ground-coil length could be cut by more than half under these conditions (from 35 m/kW (400 ft/ton) to 17.5 m/kW (200 ft/ton)) provided that the lower heat pump operating temperature does not greatly degrade system performance. Other experimental work on refrigerant-charged ground-coil systems is being carried out by Water Furnace International, a heat pump manufacturer in the U.S.A. They indicate that it will be some time before installation and material problems are overcome.

5.5 SPIRAL PLASTIC PIPE

A pipe spiral inserted into a large-diameter augered hole allows more pipe contact with the soil for a given number of holes. The diameter of the spiral and the distance between turns are the principal factors affecting the coil performance. No known performance data is available for sizing a system with a spiral ground coil. However, monitored results for conventional two-pipe (U-tube) vertical systems show that at least 15 W/m of pipe can be collected during the most demanding months of the winter. Spiral pipe, because of the interaction between adjacent turns, would collect less than this figure, especially near the end of the heating season.

For comparison purposes, a figure of 10 W/m has been estimated for a spiral 0.6 m (2 ft) in diameter with 0.3 m (1 ft) between turns. A spiral of this design would need 4.4 times more pipe than a vertical two-pipe system. Thus, on a per-metre-of-hole basis, the plastic spiral pipe would collect 2.9 times more heat than the two-pipe (U-tube) vertical system but cost 4 times more for pipe and somewhat more for augering. This makes the hole length criteria 4.5 m/kW (52 ft/ton) for an augered hole 0.6 m (2 ft) in diameter, compared to 13 m/kW (150 ft/ton) for the conventional two-pipe hole. It should be noted, however, that the volume of earth removed from the necessary length of large augered hole in the hypothetical spiral pipe system is about six times greater than the equivalent heat gathering length of drilled hole in a conventional vertical system. This volume may present a problem during the installation of the heat exchanger and may prove to be an impractical quantity of earth to move except at certain new-construction installations.

6 RECOMMENDED IMPROVEMENTS TO REDUCE COSTS

6.1 VERTICAL SYSTEMS USING MULTIPLE PARALLEL PIPES

From a drilling perspective, 2.5 cm (1 in) diameter pipe and the corresponding smaller hole diameter needed, make vertical drilling easier. The smaller pipe is also cheaper per unit length and easier to handle during installation. The major disadvantage is that parallel piping circuits must be used to reduce pressure drops, and this creates flow balancing problems especially when holes are of unequal depths. This problem can be overcome to some extent by locating the header that connects the parallel loops indoors, thus facilitating purging and filling of each loop and balancing unequal flows with a valve, if required. Reducing the pipe size to 3.2 cm (1.25 in) and using a narrow design for the U-tube fitting would allow 10 cm (4 in) holes to be utilized. This opens the drilling market to a number of rigs now operating in Ontario (e.g. hollow-stem auger and soil-sampling equipment) that could drill with existing 10 cm (4 in) equipment, thus increasing competition and helping to reduce costs.

6.2 HEAT PUMP IMPROVEMENTS

Ground-source heat pumps have the lowest operating cost of any conventional heating system. However, the quoted performance for these systems in the Toronto area is sometimes 10 to 30 per cent higher than actually measured. This is in part due to our Canadian climate which requires the units to operate at source temperatures approximately 10°C below the equipment's "rating" temperature. However, even at these cooler source temperatures, better performance figures than those measured are possible.

To achieve these higher performance figures some direction could be taken from the work carried out by Young and Lange on optimizing air-source heat pumps for northern climates (9). Their work indicated that improved heat-exchanger performance and an electronically-controlled expansion valve could increase overall efficiency by 20 to 30 per cent. GSHPs can benefit from some of these same findings in the area of evaporator design (increased or enhanced surface area) and expansion valve control. Other work that may prove helpful to manufacturers is an evaluation of numerous evaporator designs by Hawken and Hearty at NRC (10). Their conclusions stress the major impact that the choice of evaporator has on the performance of the heat pump. These results are in agreement with and complement research carried out by Catan and Baxter under contract to the U.S. Department of Energy (DOE) (11). The major conclusion of their study to optimize a ground-coupled heat pump for northern climates was that the GSHP system can be improved in a much more cost effective manner by improving the heat pump performance than by adding length to the ground coil. Their optimization was a simulation carried out for a horizontal system. Hardware is to be built based on the computer model for a field evaluation of the optimized design.

Regardless of the steps taken to improve the seasonal coefficient of performance (SCOP) the typical 2.2 to 2.7 could be increased to between 2.5 and 3.2 with some fairly simple equipment design changes. This would increase the savings by $100 to $200 per year, thus improving the GSHP cost/benefit ratio.

6.3 SECONDARY HEAT PICK-UP SYSTEMS

This Section discusses several backup heat sources that could be used to supplement the ground coil. Capital cost savings would be realized by purposely undersizing the ground coil. During colder winter periods, the secondary heat source would supply heat to the heat pump when the ground coil could not do so satisfactorily. For the integrated system to work, the secondary heat source should have the following characteristics:

- o Available when the ground-coil performance begins to drop.
- o Incorporated at low cost relative to the full-sized ground coil.
- o Inexpensive to maintain.
- o Inexpensive to operate.

Four potential secondary heat sources are listed and discussed below:

- o Outdoor Air
- o Domestic Water Supply (city or well-water)
- o Solar Energy With and Without Storage
- o Heat Recovery (Ventilation Air, Grey Water, etc.)

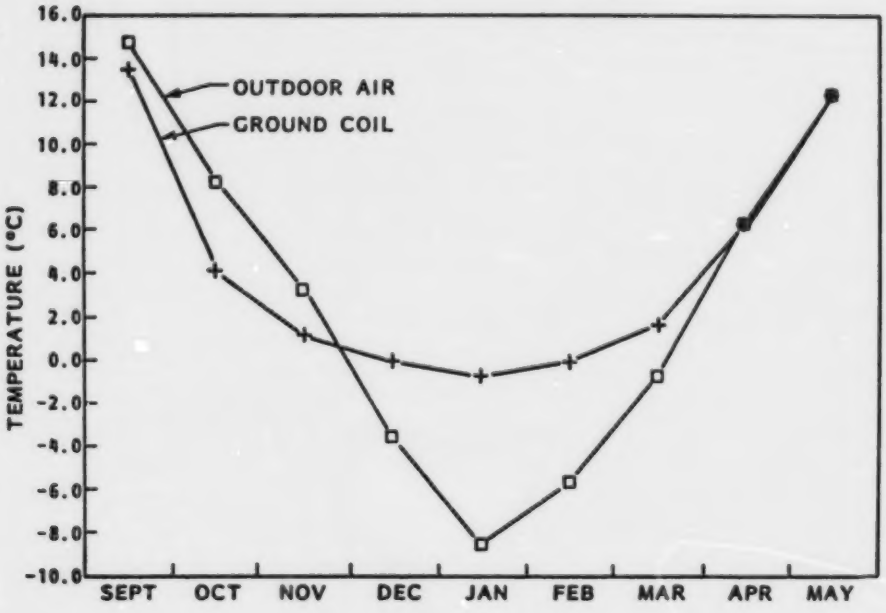

FIGURE 5

AVERAGE MONTHLY OUTDOOR AIR AND

GROUND-COIL TEMERATURES NEAR TORONTO

Outdoor Air Backup

Toronto-area average monthly outdoor-air temperatures and corresponding ground-coil temperatures are shown in Figure 5. The ground-coil temperatures are those of a horizontal GSHP system located just north of Toronto. The measured values were recorded with the heat pump "off" and the antifreeze solution circulating. Figure 5 shows that the average outdoor temperature is lower than the ground coil by the first of December and higher by the end of March. For the rest of the heating season, the ground coil is as warm as or warmer than the outdoor air. However, the figure does not show that the ground temperatures remain stable while the outdoor air varies between 15°C and -35°C. Thus for a complete picture, the variations in outdoor-air temperature must be examined to determine the actual length of time spent above the ground-coil temperatures for each heating month.

To help in this regard, hourly air-temperatures based on 10 year averages were compiled into 3°C bins and plotted as a percentage of the total hours for each month. The graphs produced give the temperature distribution curves shown in Figure 6. Also shown on the temperature distribution curves are the times spent above and below the ground-coil temperature for the respective month.

As a general result for the months of September, October, November, and April, outdoor air is as warm as or warmer than the ground coil for approximately 50 per cent of the time. (This of course does not mean that 50 per cent of the heating load occurs while the air is above the ground coil temperature, since heat loss itself is a function of outdoor air temperature.)

For part of December and March and most of January and February, the ground coil is normally much warmer than outdoor air. However, over

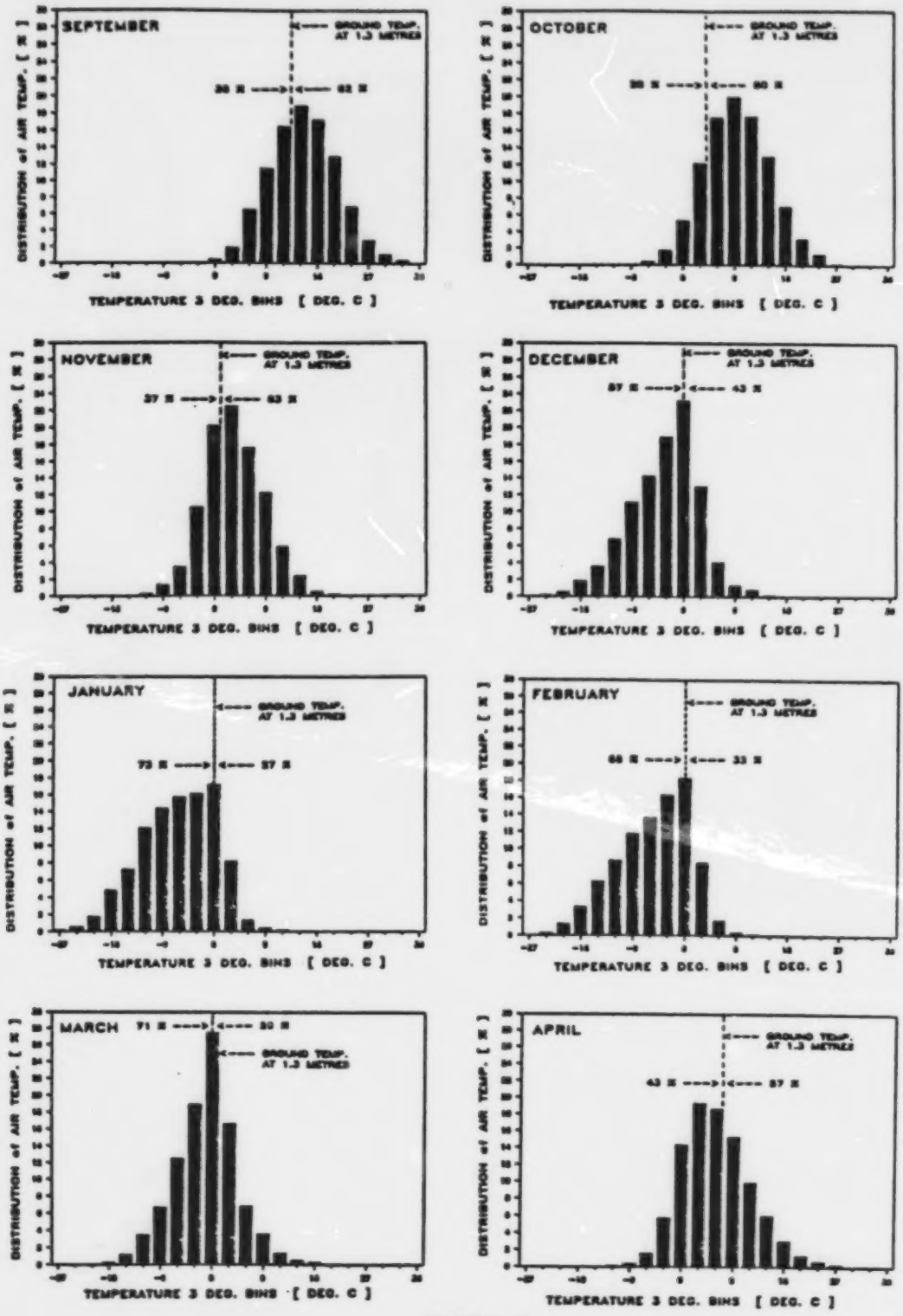

FIGURE 6

MONTHLY AIR TEMPERATURE DISTRIBUTION COMPARED TO GROUND TEMPERATURE AT 1.3 METRES

degree-hour tabulations of the Toronto heating season, it can be found that about 22% of a house's heating energy is supplied during this 35% of the time. However, the ground temperature itself is a moving target and it must be determined to know how much, if any, recharging of the ground coil can take place when the heat pump is using the warmer air temperature as a heat source. In addition to this unknown, several other questions need to be answered before conclusions can be drawn on the economics of this potential heat source. They are:

- How low will an undersized ground-coil drop in temperature during January or February when the outdoor air is seldom of benefit?

- How expensive will it be to operate the pump and fan motors required to run the heat pump or recharge the soil with heat?

- How should a system be sized?

- How should a system be implemented (air-to-freon or air-to-liquid heat exchangers)?

To answer these questions, field trials or computer simulations would be required. However, some information already suggests certain applications for the air-source backup system. Two pipes in one trench extract twice as much heat compared to a single-pipe system up to the end of February, but then the rate of heat extraction drops to 1.6 times (see section 5.2). Thus, any ground-coil system that has approximately the correct pipe length but because of it's configuration (multiple pipes in a trench, spiral pipe, etc.) experiences thermal interference (interaction) between pipes late in the heating season might benefit from air-source heat. Similarly, ground coils with better thermally-performing pipe (better transient performance, like copper pipe) could benefit from an air-source heat exchanger that reduces the thermal load for short periods of time to allow the soil temperatures surrounding the

buried pipes to recover (i.e. warm towards the far-field ground-temperature).

An example of how ground-coil systems can integrate with air-source heat exchangers is shown in Appendix A.

Domestic Water Supply (City or Well Water) Backup

For undersized ground-coil systems, there are periods of time in the winter when the performance of the heat pump drops as the antifreeze fluid of the ground coil drops in temperature. This occurs during the coldest winter periods, thus requiring auxiliary heating to be used. Instead of auxiliary heat, the heat pump output could be increased by coupling the ground coil or the heat pump refrigerant to a water-source heat exchanger. The difficulty in the design is to ensure proper freeze protection when the water-source is not used. This could be accomplished by either draining the heat exchanger when not in use or by maintaining a minimum flow when the freeze potential exists.

A design is given for the water-source heat exchanger concept in Appendix A. As with the air-source heat exchangers described above, no design criteria or test results are yet available for this concept. The economics of the system will depend on the local city water costs and water temperature. For cities drawing water from rivers or lakes, winter conditions limit the temperature drop before freezing to approximately $4^{o}C$. For cities (or individuals) drawing water from an underground aquifer, the heat pump could drop the water temperature by more than $8^{o}C$ before a freezing hazard develops. From this starting point, Appendix A shows the calculation that water and sewage costs combined must be below 25 ¢/m^3 for cold (lake) water supplies, and below 50 ¢/m^3 for aquifer (well-water) supplies. If water costs exceed the values stated above, then electric resistance backup heating, using 5 ¢/kWh electricity, would be more economical to operate. (Typical urban water and sewage charges are 54 ¢/m^3.)

Solar Backup With and Without Storage

Solar energy is a diffuse and highly variable energy source in winter. To recover this energy, solar collectors have been used in Sweden to increase the operating temperatures of conventionally sized ground-coils (12). The field results for several monitored systems indicate the annual mean temperature and annual minimum temperature of the ground coil can be increased by about 2°C compared to ground coils of the same size but without solar collectors. The increased ground coil temperatures were found to increase the seasonal performance factor (SPF) of the heat pump by 0.1. Based on this increased SPF, solar-assisted ground-coils were not cost effective in Sweden. Similar results for the Province of Ontario have been reported by Tripp (13). However, Tripp's work shows an improvement in the performance of the solar-collector system when a heat storage system is added. The optimal solar-collector area and storage volume for various electricity rates were calculated by Tripp. His results, however, have not compared the cost of the collectors and storage tank to that of a correctly sized ground coil.

Heat Recovery Backup

A multi-functional "Integrated Mechanical System" has been proposed by Allen for low energy houses (14). The system would be capable of providing space heating and cooling, domestic hot-water heating, grey-water heat recovery, and continuous ventilation with exhaust-air heat recovery. When the internal heat sources are insufficient for the mechanical system, a short ground coil or water storage tank is to be used as the heat source.

Conventional GSHPs with an antifreeze-filled ground-coil could be expanded to provide both grey-water and exhaust-air heat recovery. The latter application would address the growing concern over indoor air quality. Another approach for rural areas is to lay the ground coil

under a septic tile bed. Work carried out by EER, a mechanical contracting company in Manassas, Va., has shown the moist environment around the pipes has enhanced heat transfer and increased system performance without adversely affecting the septic field's performance (15). Other opinions in the GSHP industry suggest caution when applying this approach in colder areas were winter freezing of the bed could pose problems.

There is a growing interest in heat recovery systems for residential dwellings to help conserve energy. At the same time there is a growing concern with indoor air quality. GSHPs could play an important role in an integrated mechanical system.

7 CONCLUSIONS AND RECOMMENDATIONS

1) GSHP costs are presently about evenly split between the ground-coil installation and the equipment installed indoors. Total installation costs are about $10,000 for the Toronto area.

2) The lowest-cost drilling method (augering) can not always be selected, due to the presence of boulders or shallow bedrock in certain parts of the Province. Higher-cost methods (rotary rigs) may need to be used to guarantee success in areas were precise drilling conditions are not known. The information and maps in Appendix F can help identify problem drilling areas and favourable soil conditions. More detailed site-specific information may have to be sought in areas of varied local geology.

3) In favorable areas, auger drilling by an experienced crew can reduce costs for a vertical ground-coil GSHP system by at least $1,000 to $2,000 from the average quoted above. In less favourable areas, drilling costs can increase sharply based on soil conditions, the drill rig selected, and the drill crew's experience and "mind-set" towards GSHP systems.

4) No one drilling-rig combined high installation economy with the capability to drill in all subsurface conditions. Different rigs are more productive in certain subsurface conditions than in others. Installation economy is best achieved by selecting the drilling rig most suited to the geology at the customer's site. Modified drilling rigs that permit rapid changes in drilling methods to meet changing subsurface conditions, say from conventional to percussion, are starting to appear on the market. Use of these rigs, adapted for heat pump installation, may aid in reducing installation costs.

5) Vertical residential GSHP installations may not be able to compete with the alternatives available in Ontario's unfavourable drilling locations. New ground-coil technologies (such as smaller-diameter holes and pipes or smaller-area horizontal systems) may emerge to make GSHPs viable in these locations.

6) GSHP hardware, compared to air-source heat pump hardware, is not over priced; it is larger sized. GSHPs are normally sized close to the home's heat loss, but a move toward smaller heat pump sizes will lower the installation cost by $2,000 or more without greatly diminishing energy savings to the customer under present electricity rate structures. This capital cost saving would come at the expense of increased peak electrical demand for backup heating, thus negating the demand reduction advantage that the utility enjoys when a GSHP is chosen rather than an air-source heat pump or resistance heating.

An analysis of the benefit of this demand reduction will be necessary to determine if the product has sufficient strategic conservation potential to warrant financial assistance by the appropriate authorities.

7) Accurate performance and sizing data is required for a number of innovative ground-coil designs. Field trials, similar to those conducted in northern New York, would fine tune the ground-coil sizing procedures for Ontario and obtain useful design information on new configurations.

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8. Svec, O.J., Goodrich, L.E. and Palmer, J.H.L., "Heat Transfer Characteristics of In-Ground Heat Exchangers," National Research Council, Division of Building Research, Paper No 1136, (Reprinted from Energy Research, Vol 7, 1983), Ottawa, 1983.

9. Young, D.J., Lange, H.F., "Optimization and Evaluation of a Northern Climate Residential Air-Source Heat Pump," Canadian Electrical Association Contract No. 76-12.

10. Hawken, P.J., Hearty, P.F., "Testing of Water-To-Refrigerant Evaporators for Residential Heat Pump Systems," National Research Council of Canada, NRC No. 24201.

11. Catan, M.A., Baxter, V.D. "An Optimized Ground-Coupled Heat Pump System Design for Northern Climate Applications," ASHRAE Paper H1-85-24-No. 2, June 1985.

12. Larsson, M., Spante, L., "Solar Charging of Energy Wells for Small Heat Pump Systems," Intersol 85, Biennial Congress of the International Solar Energy Society (ISES) June 23-29, 1985, Montreal, Canada.

13. Tripp, B., "A Feasibility Study of a Solar Source Heat Pump Using Seasonal Ice Storage," Sunfest '83 Windsor, Ontario, 1983. (Solar Energy Society of Canada Annual Conference)

14. Allen, G., Kani, M., "Integrated Thermal Storage in Energy Systems for Canadian Low Energy Houses," Enerstock 85, September 22, Toronto.

15. Article in, "Air Conditioning Heating & Refrigeration News", Technical Information Available by Writing to EER, 10105 Residency Rd., Manassas, Va., 22110.

APPENDIX A

GROUND-COIL DESIGNS

Vertical Pipe Configurations

Typical ground-coil pipe configurations are given in Figures A1 and A2 for both parallel- and series-connected pipe. The figures are from schematic drawings submitted by Parker at a January 1985 GSHP Workshop (6). The pipe sizes and sizing criteria shown on the figures are applicable for southern Ontario. Local geology and pipe size selection may require changes to be made to the recommended pipe lengths. Heat pump suppliers generally have case history information and/or computer programs to calculate the required pipe lengths and recommend pipe sizes for a given job.

Figure A3 schematically shows a spiral pipe ground-coil design. To make the system practical to install, the spiral loops would need to be less than 20 m meaning more than the two spiral loops shown would be used.

Horizontal Pipe Configurations

Figures A4, A5, A6 and A7 schematically show the typical pipe configurations used for horizontal systems. The most common configuration is the series connected one-pipe-in-a-trench system. The pipe size is normally 3.2 cm (1.25 inch). Either polyethylene or polybutylene is the most commonly used pipe. PVC tubing (3.2 cm ID), supplied by Plastoflex (an Ontario based company), has also been used for horizontal systems.

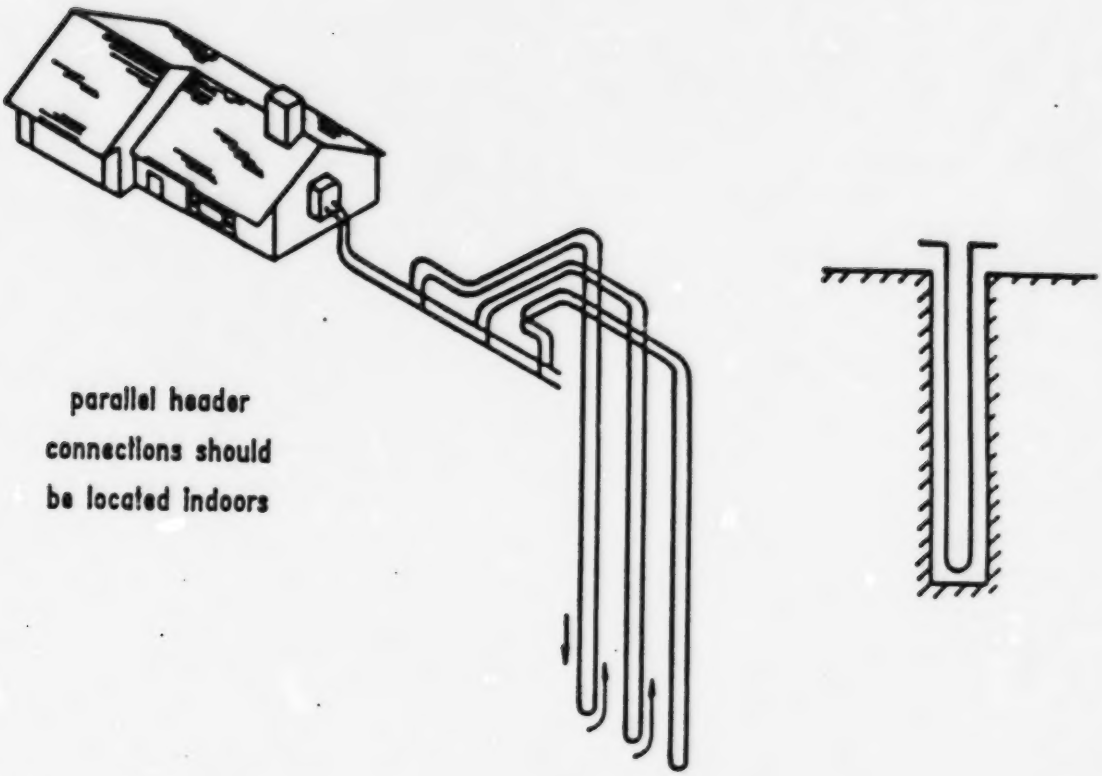
Secondary Heat Pick-up Systems

Figure A8 schematically shows one possible way that an air-source heat exchanger could supplement an undersized ground-coil. For the concept to become accepted, the air-source heat exchanger must be incorporated at a lower cost than installing the full-size ground-coil.

Figure A9 schematically shows one of several ways that a water-source heat exchanger could be utilized to supplement an undersized ground-coil. As mentioned with the air-source heat exchanger above, the water source heat exchanger must be incorporated at a low cost relative to the full-size ground-coil. In addition, the cost of city water, used by the heat pump, must be lower than the price associated with operating an auxiliary electric heating system.

For instance, if the water source heat exchanger consumed 10 liters/min. in water and dropped the supply water temperature by 4°C, then 2.8 kWh of heat is extracted every hour. This is equal to 4.6 kWh/m^3 of water consumed. Compared to 5 ¢/kWh electricity, the water and sewage charges must then be less than 25 ¢/m^3 for city water to be considered, given a temperature drop of 4°C. If the heat pump could drop the water temperature by 8°C then water costs could correspondingly increase (50 ¢/m^3). Typical urban water and sewage charges are 54 ¢/m^3 (47 ¢/m^3 for water 7 ¢/m^3 for sewage (city of Toronto 1986 rates)).

VERTICAL SYSTEM CONNECTED IN PARALLEL

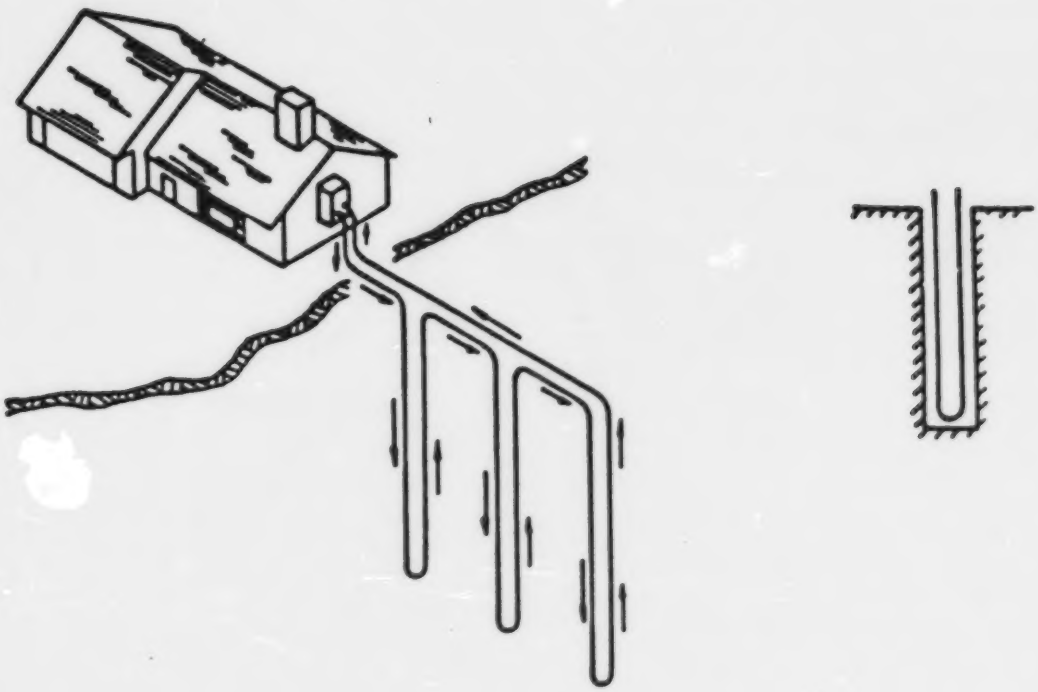


parallel header
connections should
be located indoors

Typical Pipe Sizes: 1.9 & 2.5 on (3/4 & 1 inch)
Typical Bore Length: 13 m/kW output (150 ft/ton)
Typical Pipe Length: 26 m/kW output (300 ft/ton)
Typical Bore Hole Depths: 20 to 60 m (65 – 200 ft)

Figure A1

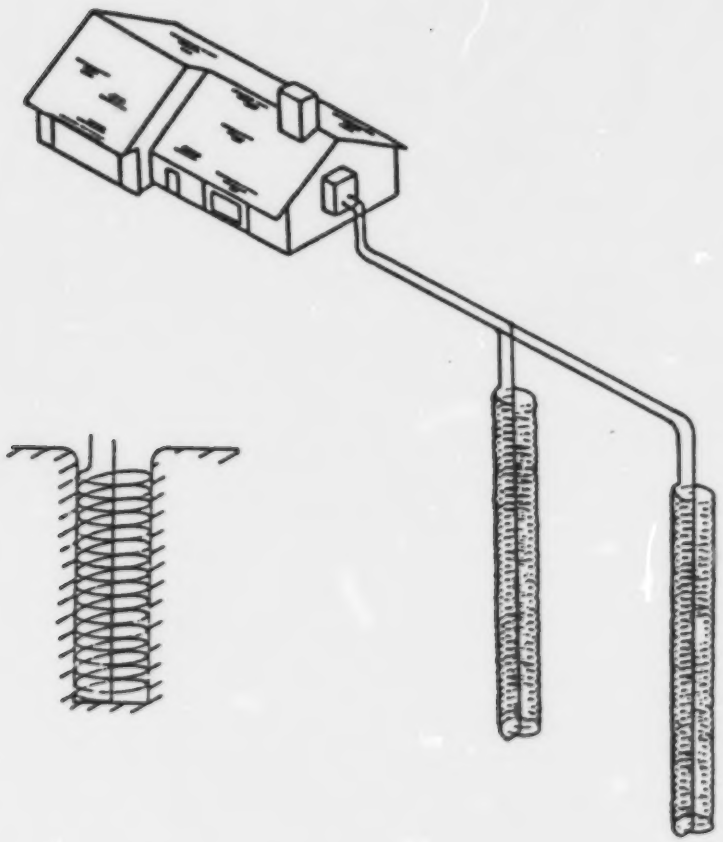
VERTICAL SYSTEM CONNECTED IN SERIES



Typical Pipe Sizes: 2.5, 3.2, & 3.8 cm (1, 1.25, 1.5 inch)
Typical Bore Length: 13 m/kW output (150 ft/ton)
Typical Pipe Length: 26 m/kW output (300 ft/ton)
Typical Bore Hole Depths: 20 to 60 m (65 – 200 ft)

Figure A2

SPIRAL PIPE IN A VERTICAL BORE HOLE

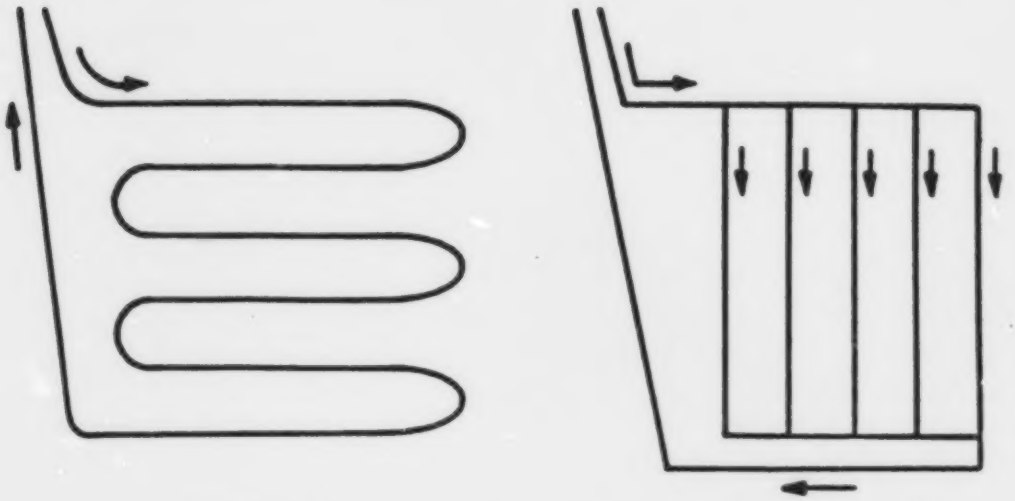


Sizing Criteria is still being determined.

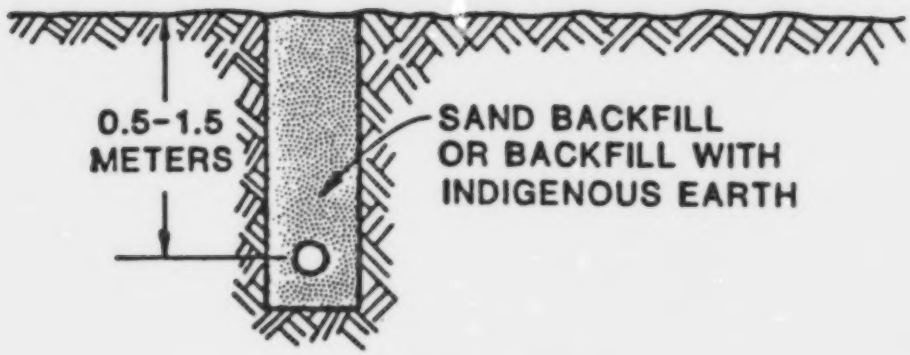
Likely bore hole length for a spiral 0.6 m (2 ft) in diameter with 0.3 m (1 ft) between adjacent pipe turns would be 4.5 m/kW (52 ft/ton) with a pipe lenght of 39 m/kW (460 ft/ton).

Figure A3

TYPES OF HORIZONTAL GROUND COUPLING SYSTEMS (8)



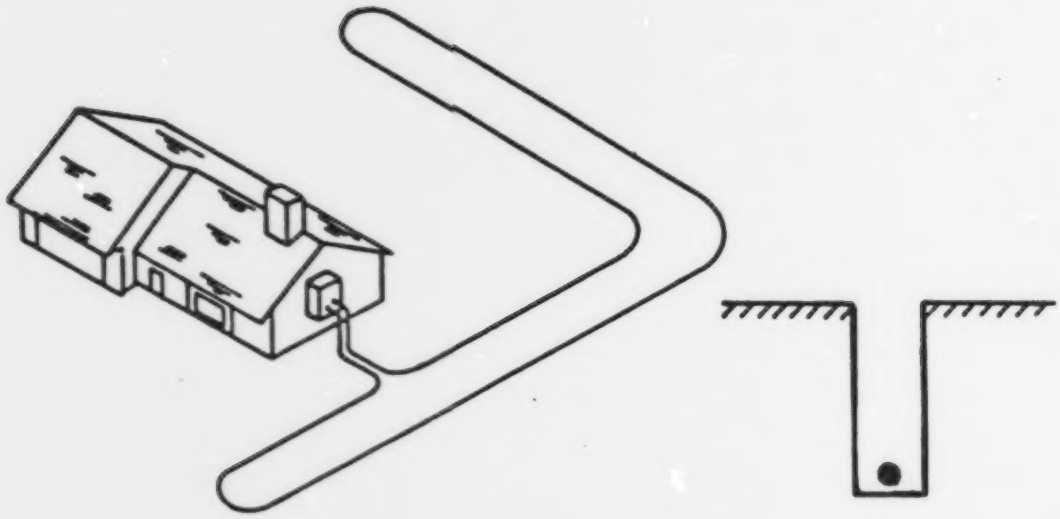
PLAN VIEW



CROSS-SECTION VIEW

Figure A4

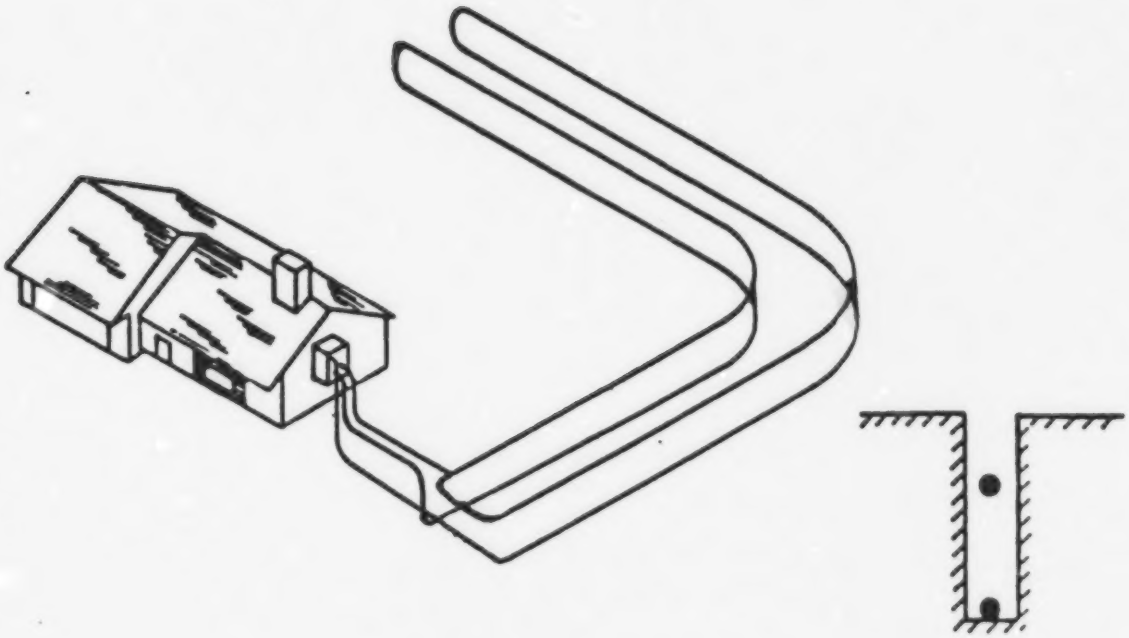
HORIZONTAL SYSTEM CONNECTED IN SERIES



Typical Pipe Sizes: 3.2 & 3.8 cm (1.25 & 1.5 inch)
Typical Pipe Length: (400 ft/ton)
Burial Depth: (1 to 2 m) (3 to 6 ft)

Figure A5

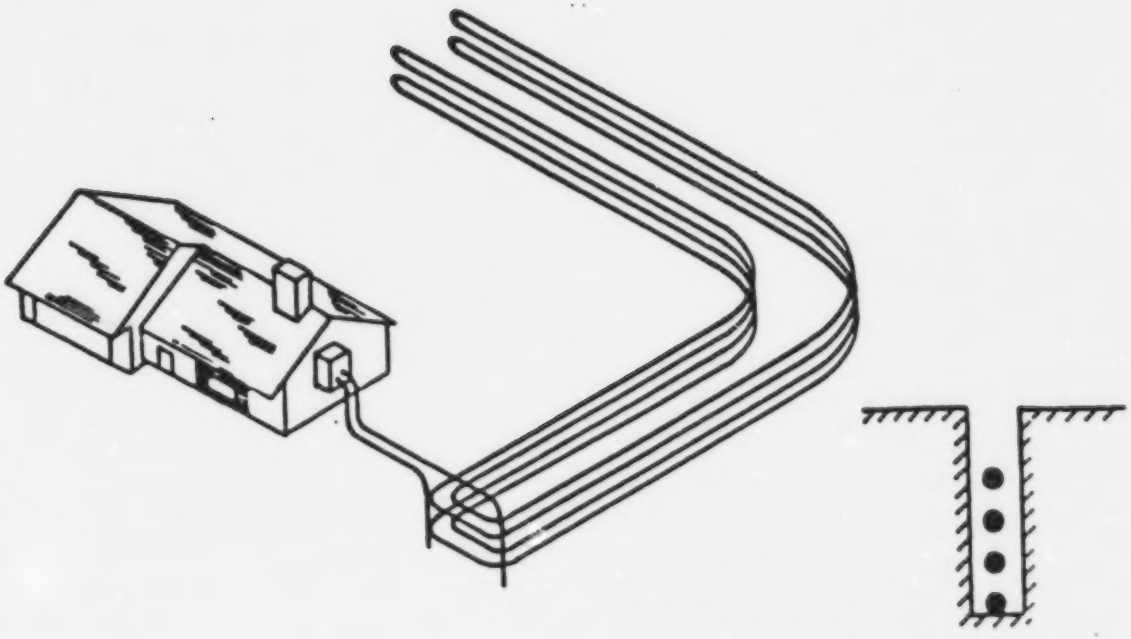
A TWO-PIPE HORIZONTAL SYSTEM CONNECTED IN PARALLEL



Typical Pipe Sizes: 2.5, 3.2, & 3.8 cm (1, 1.25, 1.5 inch)
Typical Pipe Lengths: 44 m/kW (510 ft/ton)
Burial Depth: 0.9 & 1.5 m (3 & 5 ft) respectively.

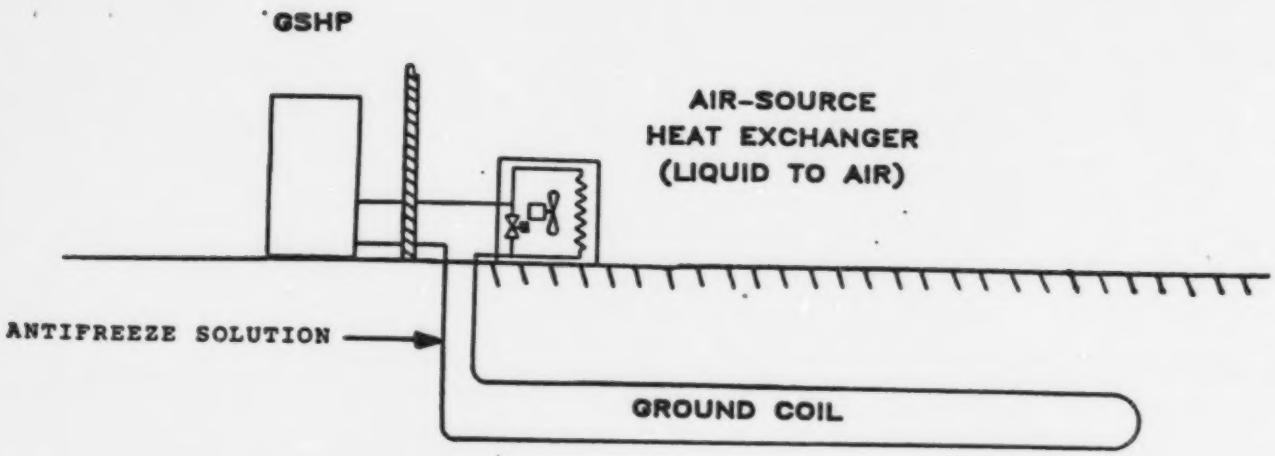
Figure A6

A FOUR-PIPE HORIZONAL SYSTEM
CONNECTED IN PARALLEL



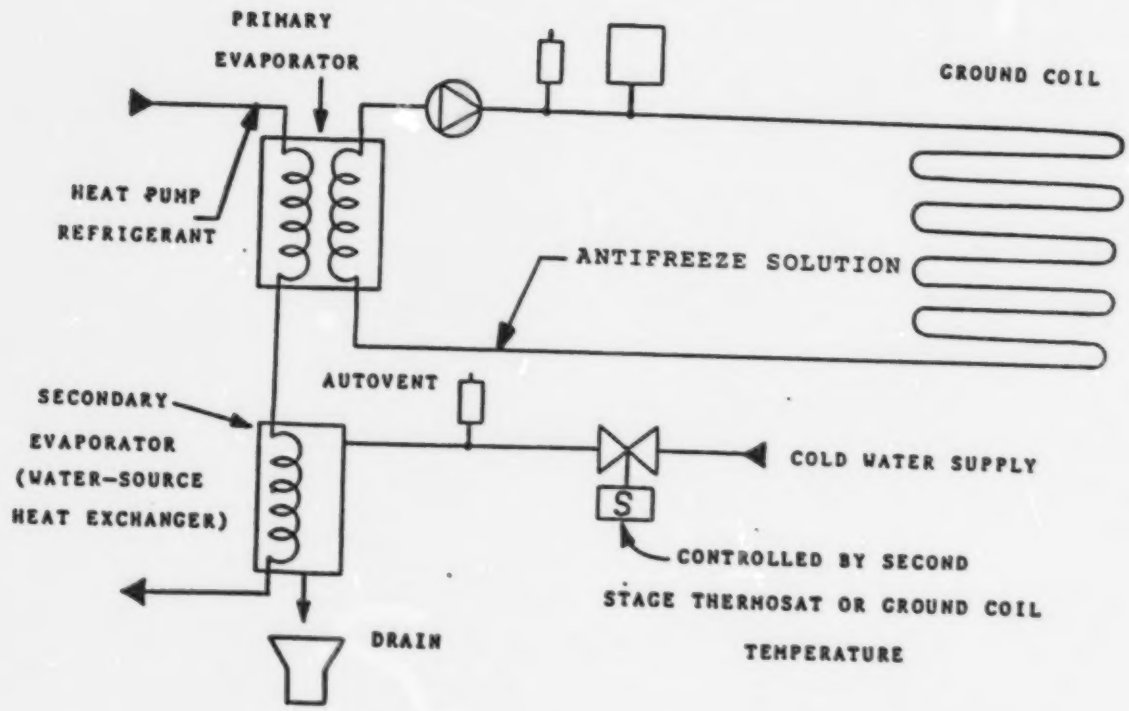
Typical Pipe Sizes: 2.5 & 3.2 cm (1 & 1.25 inch)
Typical Pipe Lengths: 52 m/kW (600 ft/ton)
Burial Depth: 2.3, 2, 1.5 & 0.7 m (8, 6, 4 & 2 ft)

Figure A7



AIR-SOURCE HEAT EXCHANGER AS
SECONDARY HEAT SOURCE

Figure A8



WATER-SOURCE HEAT EXCHANGER AS
SECONDARY HEAT SOURCE

Figure A9

APPENDIX B

LIST OF CANADIAN GSHP MANUFACTURERS

Ontario Manufacturers

1) Best Corporation
   2446 Cawthra Road, Mississauga, Ontario M5A 3K6

2) Carrier Corporation
   9 City View Drive, Toronto
   product: MPX heat exchanger on conventional air-source products

3) Earth Systems Ltd.
   124 Oak Street West, Leamington, Ontario N8H 2B6
   product: Water Furnace (wide range of residental and commerical GSHP sizes)

4) Heat Pumps of Canada
   22 Burnley Ave., Brantford, Ontario N3T 5W5
   product: Aquamatic Water Source Heat Pump

5) Marbourn Energy Research Ltd.
   Box 215, Ingersoll, Ontario N5C 3K5
   product: Enertran Heat Pump (several sizes)

Manufacturers in the Rest of Canada

1) All Tech Energy Systems Ltd.
   33 Blakely St., Moncton, New Brunswick E1C 8H7
   product: Aqua Tec (several sizes)

2) Asea Cantherm
8089 Trans Canadienne, Ville Saint-Laurent, Quebec H4S 1S4
products: DUO 520, 510, 500, 320, 310

3) Canair Equipment Inc.
305 Boul. Montpellier, Saint-Laurent, Quebec H4N 2G6
product: Permatemp

4) Delta Heat Pumps Inc.
P.O. Box 787, Amherst, Nova Scotia B4H 4B9
products: 50016W, 70016W, 35016W, 30016W

5) Rockton Energy Systems Ltd.
Rocanville, Saskatchewan, S0A 3L0

APPENDIX C

DIRECTORY OF DRILLING RIGS AND RIG MANUFACTURERS

TABLE C1

DIRECTORY OF DRILLING RIGS

Many types of rigs are available for the water well drilling industry. Drilling and Irrigation International presents this listing of top-head drive, rotary table and specialty rigs for your use.

TOPHEAD DRIVE RIGS

* Drilling & Irrigation International January-February 1985

Model Name	Drilling Depth	Rotary Head	Tophead Drive	Transport Drive	Hoisting Capacity	Mast Height	Total Weight	Pullback	Drill Pipe Diameter	Transport Height
ATLAS COPCO										
Aquadrill	270 m	-	1,960 Nm	3,220 Nm	19,600 N	7.17 m	2,250 kg	33,500 N	76-89 mm	-
B-80-22	350 m	-	8,100 Nm	3,600 Nm	27,000 N	10.00 m	5,000 kg	64,500 N	89-114 mm	-
Rotamec 50	300 m	-	7,460 Nm	3,200 Nm	19,600 N	6.14 m	2,500 kg	48,300 N	89-114 mm	-
Rotamec 1302	550 m	-	12,600 Nm	3,410 Nm	30,900 N	9.51 m	21,440 kg	16,400 N	89-168 mm	-
ARKANA EUROPE B.V.										
Conrad Min-220	75 m	-	220 kg-m	3.0 m	1,000 kg	6.0 m	3,000 kg	2,500 kg	2⅜-2⅞ in.	-
Conrad Combi-71	150 m	-	560 kg-m	3.8 m	1,700 kg	7.3 m	6,000 kg	5,000 kg	2⅜-5 in.	-
Conrad Combi-500	250 m	-	560 kg-m	4.0 m	2,000 kg	10.3 m	8,000 kg	6,500 kg	2⅜-5 in.	-
Conrad Combi-800	400-450 m	-	800 kg-m	3.95 m	3,000 kg	10.5 m	10,000 kg	8,000 - 16,000 kg	2⅞-5½ in.	-
Conrad Gull-1000	500 m	-	1,225 kg-m	3.6 m	3,000 kg	10.5 m	16,000 kg	15,000 kg	2⅞-5½ in.	-
BRAINARD-KILMAN										
Mud Bug I	300-400 ft.	325 rpm	-	-	2,000 lbs	23 ft	14,500 lbs	5,000 lbs	2¾-4½ in.	10 ft, 5 in.
Mud Bug II	700-800 ft.	180 rpm	-	-	10,000 lbs	32 ft	18,600 lbs	10,000 lbs	2¾-4½ in.	10 ft, 5 in.
DANDO DRILLING SYSTEMS LTD.										
Gofer 110	60 m	600 rpm	-	-	2,000 kg	4.8 m	1,250 kg	2,000 kg	2⅜ in.	1.5 m
Dando 220	120-200 m	200/800 rpm	-	-	8,150 kg	-	10,000 kg	7,500 kg	-	4 m
Dando 250	200-350 m	250 rpm	-	-	10,000 kg	9.1 m	6,250 kg	10,000 kg	-	3.5 m
DRILLTECH INC.										
D25K-II	450 m	106 rpm	5,808 Nm	-	-	9.19 m	13,068 kg	13,077 kg	8.89-11.43 cm	2.84 m
D40K-IIW	763 m	106 rpm	6,780 Nm	-	-	10.87 m	25,424 kg	22,700 kg	11.27 cm	4.07 m
D40K-IID	763 m	106 rpm	6,780 Nm	-	-	10.88 m	26,650 kg	27,240 kg	11.27 cm	4.07 m
DH-II	1,525 m	106 rpm	6,780 Nm	-	-	15.76 m	32,883 kg	40,910 kg	11.27 cm	4.27 m
GEORGE E. FAILING CO.										
F-5	500 ft	125 rpm	2,500 ft-lbs	-	10,000 lbs	18½ ft	-	10,000 lbs	2⅜ in.	-
F-20	2,000 ft	750 rpm	5,300 ft-lbs	-	60,000 lbs	54 ft	-	60,000 lbs	5½ in.	-
GLOBAL DRILLING SUPPLIERS INC.										
Nor-Drill E-500x6	150 m	140 rpm	-	-	6,000 lbs	9 m	-	8,000 lbs	2⅜ in.	3.15 m
HANDS-ENGLAND DRILLING LTD.										
HE 20	132 m	-	-	-	2,000 kg	-	-	-	3½ in.	-
HE 35	231 m	-	-	-	3,500 kg	-	-	-	3½ in.	-
HE 50	330 m	326 rpm	-	-	5,000 kg	-	-	-	3½ in.	-
HE 90	594 m	458 rpm	-	-	9,000 kg	-	-	-	5 in.	-
HE 175	1,539 m	187 rpm	-	-	17,500 kg	-	-	-	5 in.	-
HYDREQ LTD.										
Gryphon 45	1,000 m	200 rpm	1,650 kg-m	-	45,000 kg	12.0 m	40,000 kg	34,000 kg	90-150 mm	4.2 m
Gryphon 20	600 m	200 rpm	1,100 kg-m	-	20,000 kg	9.2 m	30,000 kg	12,700 kg	90-150 mm	4.2 m
Gryphon 16	550 m	200 rpm	1,100 kg-m	-	16,000 kg	9.2 m	30,000 kg	12,700 kg	90-150 mm	4.2 m
Minor 9	450 m	400 rpm	825 kg-m	-	9,000 kg	9.9 m	28,000 kg	9,000 kg	90-150 mm	4.2 m
Minor 7	350 m	400 rpm	825 kg-m	-	7,000 kg	8.5 m	28,000 kg	7,000 kg	90-150 mm	4.2 m
Minor 5	300 m	400 rpm	825 kg-m	-	5,000 kg	7.5 m	25,000 kg	5,000 kg	90-150 mm	4.0 m
Javelin	100 m	400 rpm	400 kg-m	-	9,000 kg	6.3 m	15,000 kg	3,000 kg	90-115 mm	3.5 m
Triton	50 m	250 rpm	550 kg-m	-	3,000 kg	4.0 m	10,000 kg	3,000 kg	90-150 mm	3.5 m

INGERSOLL-RAND										
TH-10	200 m	-	-	-	-	-	-	-	-	-
NOSSFELD MANUFACTURING CO.										
Exploratory Rock Drill	46 m	-	-	-	-	5 m	590 kg	-	28 mm	1.5 m
GUS PECH MANUFACTURING CO.										
Brat 22 Augerdrill	400 ft	140 rpm	10,000 ft-lbs	-	10,000 lbs	22 ft	11,500 lbs	18,412 lbs	12 in.	12 ft.
Brat 22 Rotary drill	1,000 ft	140 rpm	10,000 ft-lbs	-	10,000 lbs	22 ft	15,000 lbs	18,412 lbs	4¾ in.	12 ft.
PILCON ENGINEERING LTD.										
Traveler 30 MK II	150 m	-	207 kg-m	-	4,430 kg	3/6 m	2,600 kg	4,430 kg	85 mm	2.5 m
Traveler 50	327 m	-	310 kg-m	-	3,960 kg	6 m	2,640 kg	3,960 kg	100 mm	2.43 m
SCHRAMM, INC.										
TM 140 Rotadrill	1,524 m	140 rpm	-	-	63,492 kg	15.34 m	34,467 kg	63,492 kg	4½ in.	4.11 m
T660 Rota-drill	366 m	130 rpm	-	-	16,326 kg	10.05 m	19,955 kg	16,326 kg	4½ in.	3.53 m
T685H Rotadrill	549 m	170 rpm	-	-	19,958 kg	10.94 m	24,948 kg	19958 kg	4½ in.	3.78 m
T685DHH Rotadrill	914 m	170 rpm	-	-	31,760 kg	10.94 m	25,850 kg	31,760 kg	4½ in.	3.78 m
TM 90 Rotadrill	1,067 m	140 rpm	-	-	40,816 kg	15.34 m	32,653 kg	40,816 kg	4½ in.	4.11 m
T450 Rota-drill	-	-	5,988 Nm	-	8,163 kg	-	-	8,163 kg	-	-
SOUTHERN IOWA MANUFACTURING CO.										
5000 WS	300 m	-	350 kg-m	-	9,000 kg	10 m	12,000 kg	6,000 kg	76-127 mm	3.35 m
5000 AV	300 m	-	692 kg-m	-	9,000 kg	10 m	16,000 kg	8,000 kg	76-127 mm	3.35 m

ROTARY TABLE DRILLING RIGS

Model Name	Drilling Depth	Rotary Table	Mast Height	Total Weight	Drill Pipe Diameter	Hoisting Capacity	Pullback	Transport Height
DRESSER DRILLING EQUIPMENT								
Model T-70W	900 m	-	12.67 m	-	114 mm	31,780 kg	31,780 kg	4.0 m
GEORGE E. FAILING CO.								
Stratmaster 150	8,000 ft	225 rpm	97 ft	125,000 lbs	4½ in.	250,000 lbs	250,000 lbs	15 ft
Stratmaster 100	5,000 ft	250 rpm	97 ft	105,000 lbs	3½ in.	18,030 lbs	144,000 lbs	15 ft
Model 3500	3,500 ft	250 rpm	65 ft	70,000 lbs	3½ in.	16,600 lbs	100,000 lbs	15 ft
Model 3000-CF	3,000 ft	163 rpm	63 ft	80,000 lbs	4½ in.	16,600 lbs	100,000 lbs	15 ft
Model 2500	5,000 ft	163 rpm	58 ft	58,000 lbs	3½ in.	15,000 lbs	67,500 lbs	13½ ft
Model 2000-CF	2,500 ft	163 rpm	58 ft	61,000 lbs	2⅞ in.	15,000 lbs	64,000 lbs	13½ in
Model CF-15	1,500 ft	220 rpm	38 ft	40,000 lbs	2⅞ in.	15,000 lbs	26,666 lbs	11½ ft
Model 1500	1,500 ft	220 rpm	42 ft	22,500 lbs	2⅞ in.	15,000 lbs	26,600 lbs	11½ ft
Model 1250 CFD-1B	1,250 ft	220 rpm	38 ft	27,000 lbs	2⅞ in.	13,500 lbs	16,666 lbs	11½ ft
Model JED-A	1,000 ft	250 rpm	58 ft	37,500 lbs	4½ in.	60,000 lbs	60,000 lbs	11 ft, 8½ in.
Model 3000-HD	3,000 ft	163 rpm	87 ft	85,000 lbs	4½ in.	16,600 lbs	100,000 lbs	15 ft
GUS PECH MANUFACTURING CO.								
Super George H-48/H-51	120 ft	-	35 ft	25,000 lbs	-	14,000 lbs	14,000 lbs	12 ft, 10 in.
PILCON ENGINEERING LTD.								
Wayfarer 1500	150 m	-	5 m	1,000 kg	300 mm	1,500 kg	1,500 kg	1.5 m
Wayfarer	138 m	-	6 m	2,200 kg	375 mm	2,000 kg	2,000 kg	2.6 m
REEDRILL INC.								
R-75	1,070 m	-	15.3 m	33,340 kg	11.4 cm	34,020 kg	34,020 kg	4.1 m
SPEEDSTAR								
SS 1000	229 m	-	9 m	-	73 mm	5,897 kg	-	-
SS 80	2,438 m	-	27 m	-	114 mm	86,409 kg	-	-

SPECIALTY RIGS

Model Name	Drilling Depth	Total Weight	Mast Height	Drill Pipe Diameter	Pullback	Hoisting Capacity	Transport Height
DANDO DRILLING SYSTEMS LTD.							
Dando 150	75 m	2,210 kg	5.5 m	-	1,500 kg	6,000 kg	1.5 m
Dando 200 Cable Tool Rig	100 m	1,950 kg	7.6 m	-	1,500 kg	1,500 kg	2.25 m
Dando 400 Cable Tool Rig	250 m	4,250 kg	11 m	-	2,700 kg	8,500 kg	2.7 m
Dando 800 Cable Tool Rig	450 m	5,270 kg	12 m	-	4,000 kg	10,000 kg	2.65 m
DEEP ROCK MANUFACTURING							
CTM 10,000 Vulcan	100 m	920 kg	3.5 m	76 mm	-	-	1.9 m
Hydra-Drill 202P	60 m	323 kg	2.4 m	0.75 in.	-	100 kg	-
GLOBAL DRILLING SUPPLIERS, INC.							
Model 24	480 m	3,314 lbs	11.4 m	-	-	9,375 lbs	-
HALIFAX TOOL CO. LTD.							
Varitock Rig V866	-	24,000 kg	11.75 m	115 mm	15,750 kg	30,000 kg	4.35 m
HOLE-OPENERS, INC.							
Hole Openers	-	90.7-800 kg	-	-	-	-	-

TABLE C2

ADDITIONAL DRILLING RIG DATA

MANUFACTURER & Model Number	Drilling Depth (m)	Rotary Speed (rpm)	Tophead Drive (N-m)	Downfeed Force (kg)	Hoisting Capacity	Mast Height (m)	Total Weight (kg)
SIMCO							
2400 SK1	20 - 25	140	880	2,700	-	4.5	2,000
4000 TR2	60	-	3,400	3,800	-	6.0	7,000
CENTRAL MINE EQUIP							
750	75	-	11,500	-	-	7.6	9,000
GARDNER DENVER (wet auger)	-	130	-	-	-	2.3	5,000
DEEP ROCK							
Flamingo	-	130	850	2,600	8,500 lb	3.8	1,100
JKS BOYLES							
B30-H	1000	950	4,700	9,100	15,000 lb	6.1	13,600
MOBILE							
B-31	40	418	4,400	3,600	4,800 kg	4.5	5,000
B-61	75	583	12,100	7,200	9,600 kg	10.0	9,000
BORROS							
Polhydrill	100	75	-	7,200	-	5.0	1,600

Source: Ontario Hydro Research Division

TABLE C3

DIRECTORY OF RIG MANUFACTURERS

Atlas Copco
S-105 23
Stockholm, Sweden
446 (0) 8 7438000
Telex: 14090

Arkana Europe B.V.
JoH. Van Soe
Sdijkstraat 37
P.O. Box 286
Diemen 1110 A.G.
The Netherlands

Brainard-Kilman
P.O. Box 487
Tucker, GA 30085 U.S.A.
Telex: 542 969

Dando Drilling Systems Ltd.
River Road, Littlehampton
West Sussex BN13 1BH
England

Deep Rock Manufacturing
225 Anderson Rd.
Opelika, AL 36802 U.S.A.

Dresser Drilling Equipment
P.O. Box 505
Marion, OH 43302 U.S.A.
(614) 383-5211

Driltech, Inc.
P.O. Box 338
Alachua, FL 32615 U.S.A.
(904) 462-4100
TWX 568-441

George E. Failing Co.
P.O. Box 872
Enid, OK 73702 U.S.A.
(405) 234-4141
Telex: 769-524

Global Drilling Suppliers, Inc.
P.O. Box 67
Harrison, OH 45030 U.S.A.
(513) 367-9594
TWX: 4608 371

Halifax Tool Co. Ltd.
South Owram Halifax
West Yorkshire
HX3 9TW
United Kingdom

Hands-England Drilling Ltd.
Flint Road
Letchworth Herts SG6 1HH
England
(44) 4626-72025
Telex: 826 435 HEQUIP G

Hole-Openers, Inc.
P.O. Box 556
Industrial Pack Road
Benton, IL 62812 U.S.A.
(618) 439-6385
Telex: 406 440

Hydreq Ltd.
Imperial Buildings
Victoria Road, Horley
Surrey RH6 7QA
United Kingdom
(02934) 71501-8
Telex: 877 475

Ingersoll-Rand
Dept. NR-83
253 E. Washington Ave.
Washington, NJ 07882 U.S.A.

Nossfeld Manufacturing Co.
P.O. Box 557
Winona, MN 55987 U.S.A.

Gus Pech Manufacturing Co., Inc.
P.O. Box 96
LeMars, IA 51031 U.S.A.
Telex: 703 176

Pilcon Engineerng Ltd.
Stephenson Road
Houndmills
Basingstroke, Hants
RG21 2XP
United Kingdom

Reedrill Inc.
800 Box 998
Sherman, TX 75090 U.S.A.

Schramm Inc.
800 E. Virginia Ave.
West Chester, PA 19380 U.S.A.

Southern Iowa Manufacturing Co.
P.O. Box 448
Osceola, IA 50213 U.S.A.

Speedstar
P.O. Box 3869
Enid, OK 73702 U.S.A.
(405) 234-3737

APPENDIX D

HOLLOW-STEM-AUGER FIELD-TRIAL SUMMARY

Purpose

Dry-augering equipment was believed to have significant potential for economic installation of ground coils. This equipment is not often used for heat pump work now because of a mismatch between coil size (11 cm) and the normal drill hole size (10 cm). The conventional use of these rigs for soil sampling (a start-stop drilling process) did not lend itself well to predicting ground-coil installation productivity (a continuous drilling process). To acquire the desired information, a field drilling trial was performed using a CME 750 drill rig and hollow-stem augers (see Figures D1 to D3).

By removing the end plug, hollow-stem augers become the casing for the hole. Hollow-stem augers allow coils to be installed in caving soils without the use of drilling mud. The drill rigs for operating this equipment are generally smaller and more maneuverable than conventional- or mud-rotary drills, while performing a similar function, so they should have an advantage in retrofitting GSHP's in old neighborhoods.

Drilling Site and Program

The drilling was performed on a site just east of Buttonville Airport in late 1985. One hole was drilled to a depth of 100 feet (30 m) in soil, and a 2 inch (5 cm) diameter pipe was installed through the centre of the hollow-stem augers to represent a ground-coil installation. The time taken for the entire installation and for component activities was measured in some detail. Soils at the site were predominantly sands and silts, wet at depth, which could be classed as easy drilling. Inside diameter of the hollow stems was 4 1/8 inches (10.5cm).

Discussion of Results

The time summary for the test is shown in Table D1. Total installation time required was 433 minutes for a productivity rate of about 14 feet per hour (4.2 m/hr). Rates of advancing the hole ranged from 21 to 50 ft/hr (6.4 - 15.2 m/hr) even with the significantly large portion of time required to couple the auger segments included. Overall, the drilling time to advance the hole totalled 178 minutes for an average productivity of 33.7 ft/hr (10.3 m/hr). It was the time of 160 min to pull the augers from the hole, and clean them, that reduced the overall productivity to its final low value.

It was anticipated that the hollow-stem auger equipment would perform at a rate competitive with conventional equipment (i.e. costs in the $5 to $7 per foot range and productivity in the 20 to 25 foot per hour range). The test cost ($8.53 per foot) and productivity (14 feet per hour) did not meet expectations. Unless dry-auger machine operators can improve their productivity and cost competitiveness, this test demonstrated that conventional or wet-auger methods should be selected for ground-coil installation.

TABLE D1

Drilling Time Analysis:

Set Up Time -	move drill on site	20 min.	40 min.
	erect boom	20 min.	
Drilling Time -	advancing hole	approx. 98 min.	178 min.
	- adding augers	approx. 80 min.	
	- pull tooth auger	15 min.	
	- pulling augers (after pipe installed)	160 min.	
Installing Pipe (after tooth auger pulled)		10 min.	
Demobilize Drill to Trailer		30 min.	
Breaks (coffee, lunch)		approx. 30 min.	
Down Time -	wet, won't start	20 min.	
	- (2/3 day due to heavy rain)	not included	
Total Installation Time (excluding downtime and breaks)		433 min.	
Productivity (100 ft hole)		13.9 ft/hr	

TIME ANALYSIS BY HOLE DEPTH

Depth	Total•	Add Augers	Drilling Rate
0 - 25'	33 min.	20 min.	45 ft/hr
25 - 50'	30 min.	20 min.	50 ft/hr
50 - 75'*	45 min.	20 min.	33 ft/hr
75 - 100'	70 min.	20 min.	21 ft/hr
	178 min.	80 min.	

* harder layer encountered

• note lowered productivity with depth

Cost Data

Drill rental	(9 hrs)	$ 432.00
Labour Component	(2 man crew)	351.00
Mobilization		70.00
Total Cost		853.00

Unit Cost: $8.53/foot drilled

FIGURE D1

CME 750 DRILL RIG MOUNTED ON
NODWELL TRACKED VEHICLE

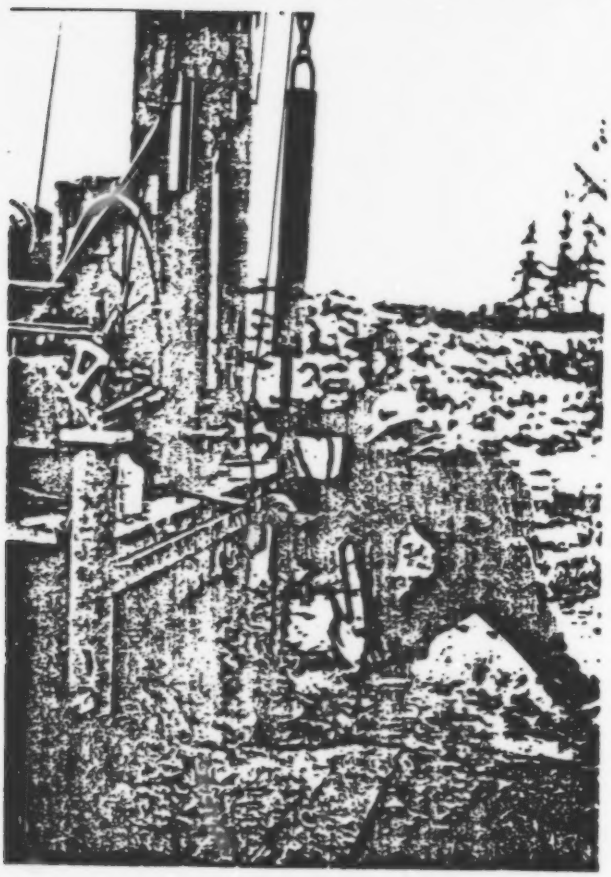


FIGURE D2

PULLING TOOTH AUGER (END PLUG)
FROM INSIDE OF HOLLOW-STEM AUGERS
PRIOR TO INSTALLING 2 INCH PIPE
"GROUND COIL"

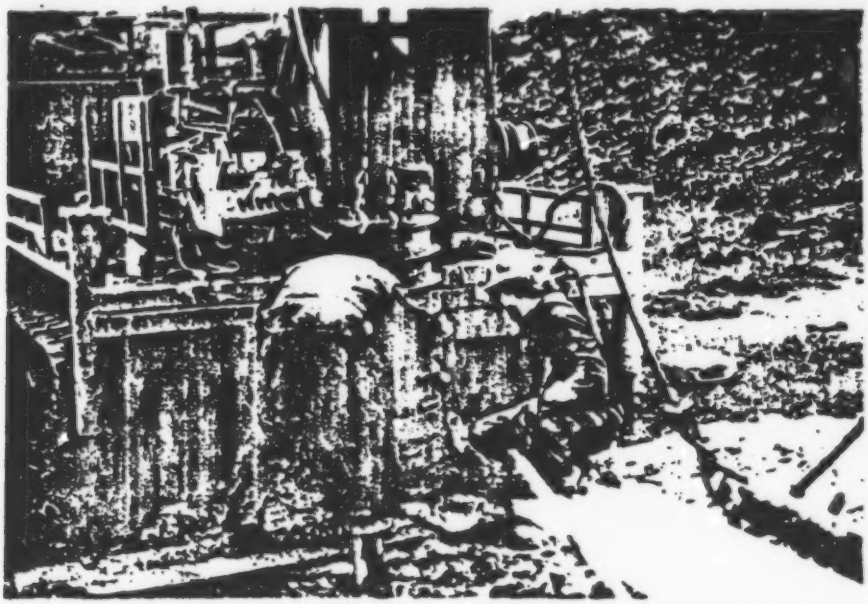


FIGURE D3

CLEANING SOIL FROM HOLLOW-STEM AUGERS
AS THEY ARE PULLED VERTICALLY, AFTER
INSTALLING "GROUND COIL"
("GROUND COIL" IS INSIDE HOLLOW STEMS)

APPENDIX E

WET AUGER PRODUCTIVITY DATA*

Project No	Location	Soil Type	Length Drilled (ft.)	No Holes	Time (hrs)	Production (ft/hr)
1	Leamington	clay	510		5	100
2	"	"	900		10	90
3	"	"	300		3	100
4	Scarborough	clay & sand	425	5	5	85
5	Toronto	sand & f. gravel	300	3	6	50
6	Mississauga	shale	400	8	30	13
7	Kleinburg	wet sand	450	6	5	90
8	"	"	800		12	67
9	"	"	600		8	75
10	Thornhill	clay	800	9	7	120

* (Source: S. Pickard, Deakin Poole, Toronto)
P. LeBeau, R & B Drilling, Goderich)

(1 ft = 0.3 m)

APPENDIX F

MAPS OF GEOLOGIC AND HYDROGEOLOGIC FEATURES IN SOUTHERN ONTARIO*

Some of the geological and hydrogeological conditions that are liable to be encountered in southern Ontario are described in the following sections and shown on the accompanying maps. The significance of these conditions to construction of vertical boreholes for ground-coupled heat pumps are discussed. These maps are not intended to be complete references for conditions in southern Ontario but are merely to be used as guides. More complete information on geologic and hydrogeologic conditions for Ontario can be obtained by referring to the references listed in Table F1. Due to the scale of the maps, local features less than 1 to 2 km across have been generalized, for clarity. The contacts listed in Table F2 may be useful in supplying site specific information. An approach to using the maps for determining drilling feasibility and selecting drilling equipment is shown in Figure F1.

Overburden Thickness (Map 1)

The overburden or soil thickness is an important factor in assessing the feasibility of constructing a vertical borehole. Bedrock is often much more difficult to drill than overburden. Usually, vertical-loop systems will be confined to areas of Ontario where there is at least 20 m or more of overburden, since this is an acceptable depth for vertical loop piping.

The map entitled "OVERBURDEN THICKNESS" shows those areas of southern Ontario where the overburden is generally less than 20 m in thickness. The predominant area where bedrock is at or near surface is on the Canadian

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*These maps should be used in conjunction with the accompanying explanatory text.

Shield and in much of eastern Ontario. There are a few other locations where bedrock is close to the surface such as in the Guelph-Brantford region and locations along the Niagara escarpment. There are other locations throughout Ontario where small areas of thin overburden exist. Detailed geologic maps and water-well records for the area of interest should be consulted if there is any uncertainty.

Flowing Well Areas (Map 2)

Flowing conditions occur when the confining pressures of the overlying geologic materials force ground-water up the borehole to the surface. If these conditions are encountered during drilling without the proper precautions and/or equipment, uncontrolled flow to surface can occur. This could result in flooding and a great deal of expense; first, to stop the flow, and second, to clean up any water damage.

The map entitled "FLOWING WELL AREAS" shows areas in southern Ontario where flowing wells have been reported by licensed water-well drillers. Generally, flowing-well areas exist near stream and river valleys and near the edges of lakes. Often the confining layers are quite thick and shallow boreholes can prevent this problem from occurring if sufficient geologic data are available for planning purposes.

Surficial Materials (Map 3)

The ease and rate of drilling boreholes depends on the type of materials that are being penetrated. One of the most difficult types of overburden to drill is one containing boulders larger than about 150 mm. Once a boulder or stone is encountered by the drill bit, progress is slowed and, in some cases, further progress may be almost impossible. Certain types of small drilling rigs cannot work in stony areas with a high degree of success, although, if the boulders are scattered, there is the potential to offset the hole by a few metres and drill down past any obstructions.

The map entitled "OVERBURDEN DRILLING CONDITIONS" shows those areas where drilling can be expected to be difficult in the upper 20 m of overburden due to dense soils or boulders. The other areas shown are thought to consist of relatively uniform and stone-free soils composed of clay, silt, sand, or some combination of these materials.

Almost all types of drilling rigs can penetrate stone-free clay, silt or sand to depths of about 20 m with little difficulty. Large areas of Ontario can, therefore, have vertical-loop systems installed with small and relatively inexpensive drilling rigs.

Ground-Water Pollution Potential (Map 4)

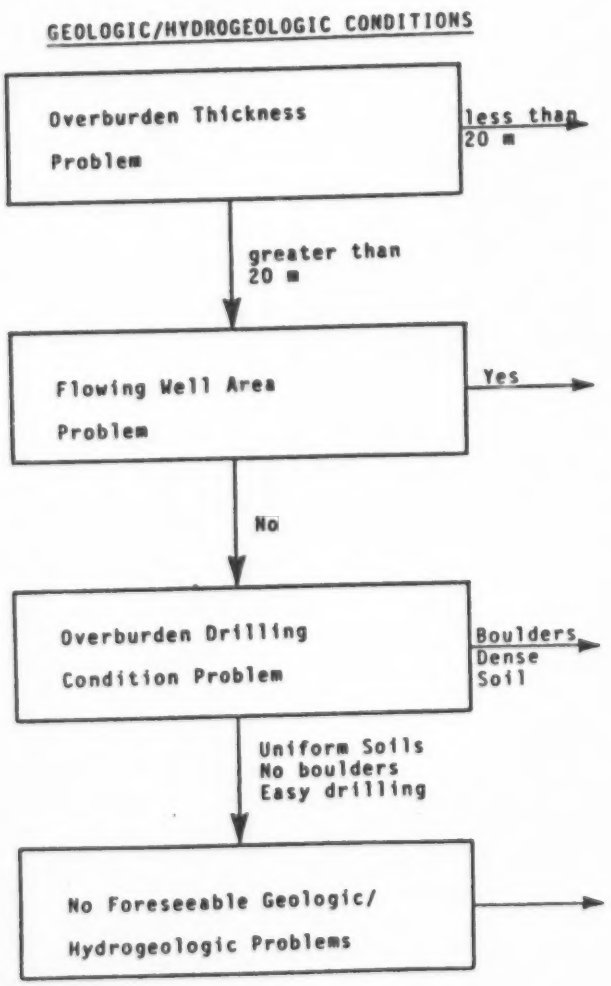
Any time a borehole is constructed, there is the potential for contaminants from the surface to be introduced into aquifers. Suitable precautions must be taken to ensure that contamination does not occur, either during the drilling process when water of poor quality may be used, or after installation of the piping when the borehole must be properly sealed to prevent downward migration of any surface contaminants.

This is especially true in those areas of Ontario where ground-water is used for domestic, municipal or commercial supplies. The map entitled "MAJOR OVERBURDEN AQUIFERS" shows the major overburden aquifers in southern Ontario. There are numerous other small aquifers scattered across the province. In Ontario, it is estimated that 11% of the water supplied to municipalities alone comes from the ground and about 98% of rural residents use ground-water (Hess, 1984).

Sealing of the boreholes can be accomplished in many ways including cement grout poured into the hole around the piping or injection of a bentonite slurry to fill the annular space between the borehole walls and the piping. Sealing of the borehole is a wise step to prevent the contamination of sub-surface waters. If contamination were to occur there is the potential for legal action against the party responsible for allowing the contamination.

Vertical Loop Installation - Feasibility Evaluation

Figure F1


GEOLOGIC/HYDROGEOLOGIC CONDITIONS
Overburden Thickness Problem
less than 20 m
greater than 20 m
Flowing Well Area Problem
Yes
No
Overburden Drilling Condition Problem
Boulders Dense Soil
Uniform Soils No boulders Easy drilling
No Foreseeable Geologic/ Hydrogeologic Problems
CONSIDERATIONS
- Many additional shallower holes may be required in overburden that is available
- Bedrock may have to be drilled
- Usually slow and expensive
- Special precautions to prevent flow during and after drilling
- May require more expensive techniques and take more time.
- Drilling may be slow and expensive
- Smaller, less expensive rigs can be used.
DRILLING RIG REQUIREMENTS *
If bedrock to be drilled, must have rock bit capability. Usually large, heavy drill rig.
Drilling rig must have mud capacity. This might be easily added to some rigs. In high pressure flowing areas, mud pumps will be needed.
Rig must have ability to deal with boulders - usually heavy rig - not augers.
Wide choice of drilling rigs

* See Appendix A - A Comparison of Drilling Rigs for Installing Vertical Loop Heat Pumps

TABLE F1

FURTHER READING

Freeman, E.B., ed., 1978
Geological Highway Map
Southern Ontario
Ontario Geological Survey,
Map 2418, Scale 1:800 000

Ontario Geological Survey, 1980
Geological Highway Map,
Northern Ontario
Ontario Geological Survey,
Map 2440, Scale 1:1 600 000

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Geology Toronto-Windsor Area
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Department of Energy Mines and
Resources, Map 1263A.
Scale 1:250 000

White, O.L., 1983
Geology of Ontario
19th Forum on the Geology of Industry
Minerals, Proceedings, Ontario
Geological Survey Miscellaneous
Paper 114, 1983, 8 p

Chapman, L.J. and Putnam, D.F., 1973
The Physiography of Southern Ontario
2nd Edition, University of Toronto Press
Accompanied by Maps 2224-2228,
Scale 1:253 400

Ontario Ministry of the Environment
1974-1979
Water Well Records for Ontario
Water Resource Bulletin Nos. 2-12
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1969-1978
Water Resources Map Series

Ontario Ministry of the Environment 1981
Flowing Wells in Ontario, 1946-1976
Water Resources Bulletin No. 2-200
Ground Water Series

Ontario Department of Mines, 1951-1961
Ground Water in Ontario

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1963-1972
Ground Water in Ontario
Ground Water Bulletin Nos. 1 to 2-11

Hess, P.J., 1984
Ground Water Use in Canada
National Hydrology Research Institute
Water Planning and Management Branch
Inland Waters Directorate
Environment Canada

Ministry of Natural Resources, 1984
Water Quantity in Ontario

Ontario Ministry of the Environment,
Water Resources Branch, 1969 - 1982,
Water Resources Report Series No. 1-15

Sibul, U.D., Walmsley, D., and
Szudy, R., 1980
Ground Water Resources in the Grand
River Basin: Grand River Basin Water
Management Study, Grand River
Implementation Committee
Technical Report Series,
Report No. 10

Table F2

USEFUL CONTACTS FOR INFORMATION

Ministry of the Environment

-Regional Hydrogeologists

Northeastern Region,
199 Larch Street,
Sudbury, Ontario. P3E 5P9
(705) 675-4501

Southwestern Region,
985 Adelaide Street South,
London, Ontario. N7E 1V3
(519) 681-3600

West Central Region,
119 King Street West,
Hamilton, Ontario. L8N 3Z9
(416) 521-7640

Central Region,
7 Overlea Blvd.,
Toronto, Ontario. M4H 1A8
(416) 424-3000

Southeastern Region,
133 Dalton Avenue,
Kingston, Ontario. K7L 4X6
(613) 549-4000

Ministry of Northern Affairs

Ontario Geologic Survey,
77 Grenville Street,
Toronto, Ontario. M5S 1B3
(416) 965-1183

Ministry of Natural Resources

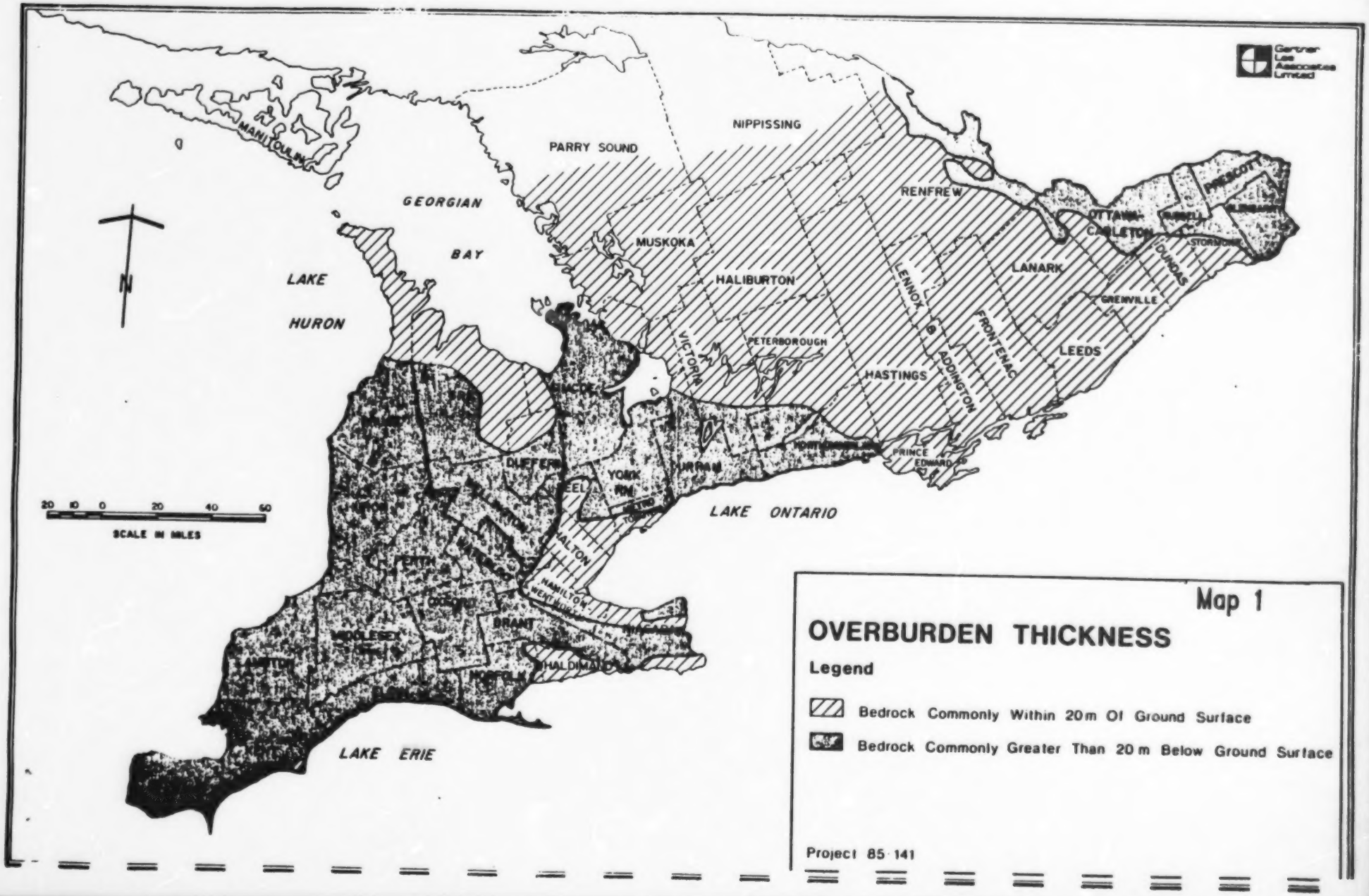
-Regional Geologists

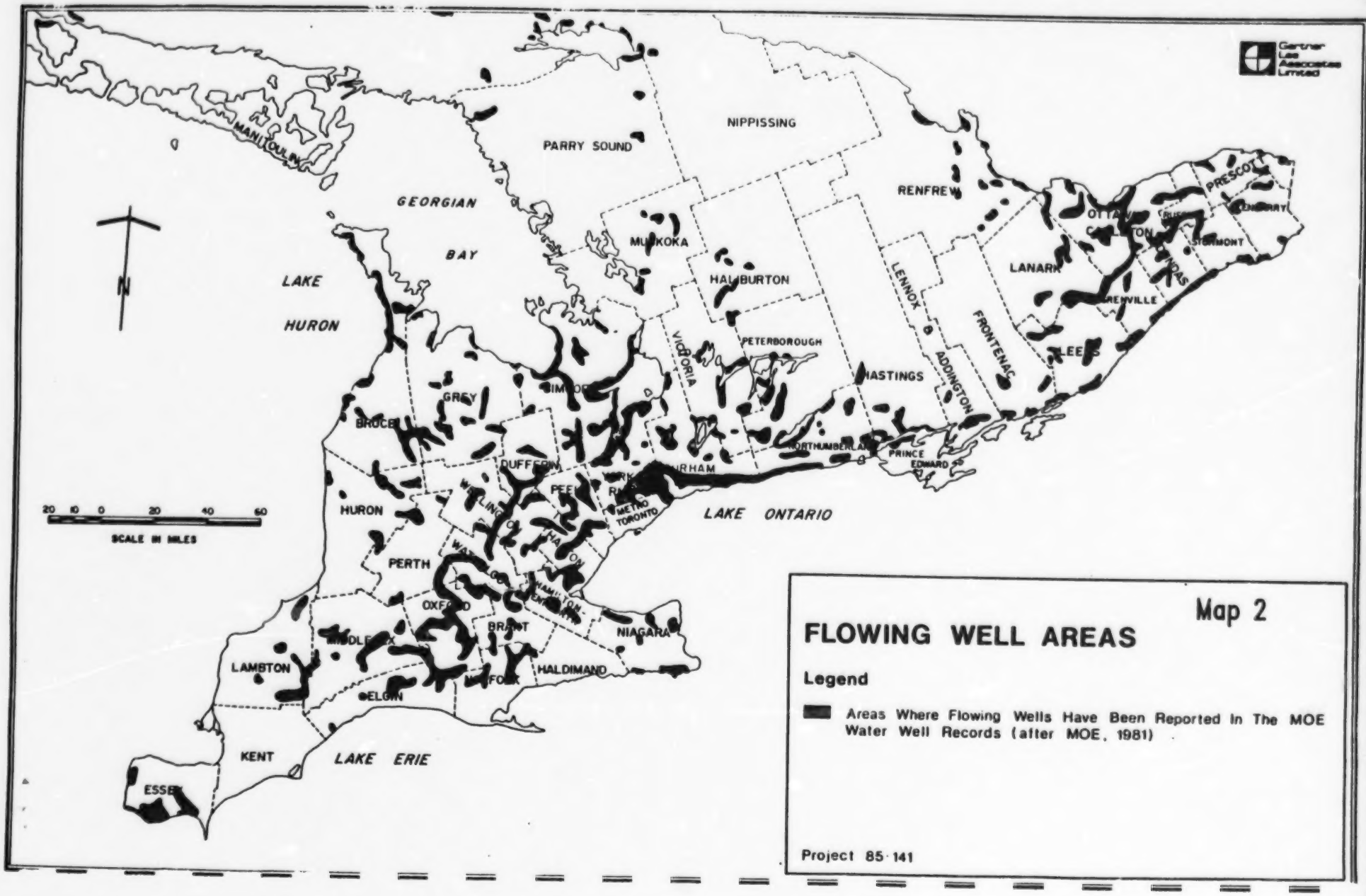
Algonquin Region,
9000 Brendale Square,
Manominee Street,
Huntsville, Ontario. P0A 1K0
(705) 789-9611

Eastern Region,
Provincial Government Building,
Kemptville, Ontario. K0G 1J0
(613) 258-3413

Central Region,
10670 Yonge Street,
Richmond Hill, Ontario. L4C 3C9
(416) 884-9203

Southwestern Region,
1106 Dearness Drive,
London, Ontario. N6E 1N9
(519) 681-5350


Gartner Lee Associates Limited
MANITOULIN
NIPPISSING
PARRY SOUND
GEORGIAN
BAY
LAKE
HURON
MUSKOKA
HALIBURTON
RENFREW
OTTAWA-CARLETON
PRESCOTT
RUSSELL
STORMONT
DUNDAS
LANARK
GRENVILLE
LEEDS
LENNOX & ADDINGTON
FRONTENAC
VICTORIA
PETERBOROUGH
HASTINGS
PRINCE EDWARD
DURHAM
YORK
PEEL
HALTON
HAMILTON-WENTWORTH
DUFFERIN
WELLINGTON
WATERLOO
PERTH
OXFORD
BRANT
NORFOLK
HALDIMAND
MIDDLESEX
ELGIN
KENT
LAKE ONTARIO
LAKE ERIE
N
20 10 0 20 40 60
SCALE IN MILES
Map 1
OVERBURDEN THICKNESS
Legend
Bedrock Commonly Within 20m Of Ground Surface
Bedrock Commonly Greater Than 20 m Below Ground Surface
Project 85-141



Map 2

FLOWING WELL AREAS

Legend

Areas Where Flowing Wells Have Been Reported In The MOE Water Well Records (after MOE, 1981)

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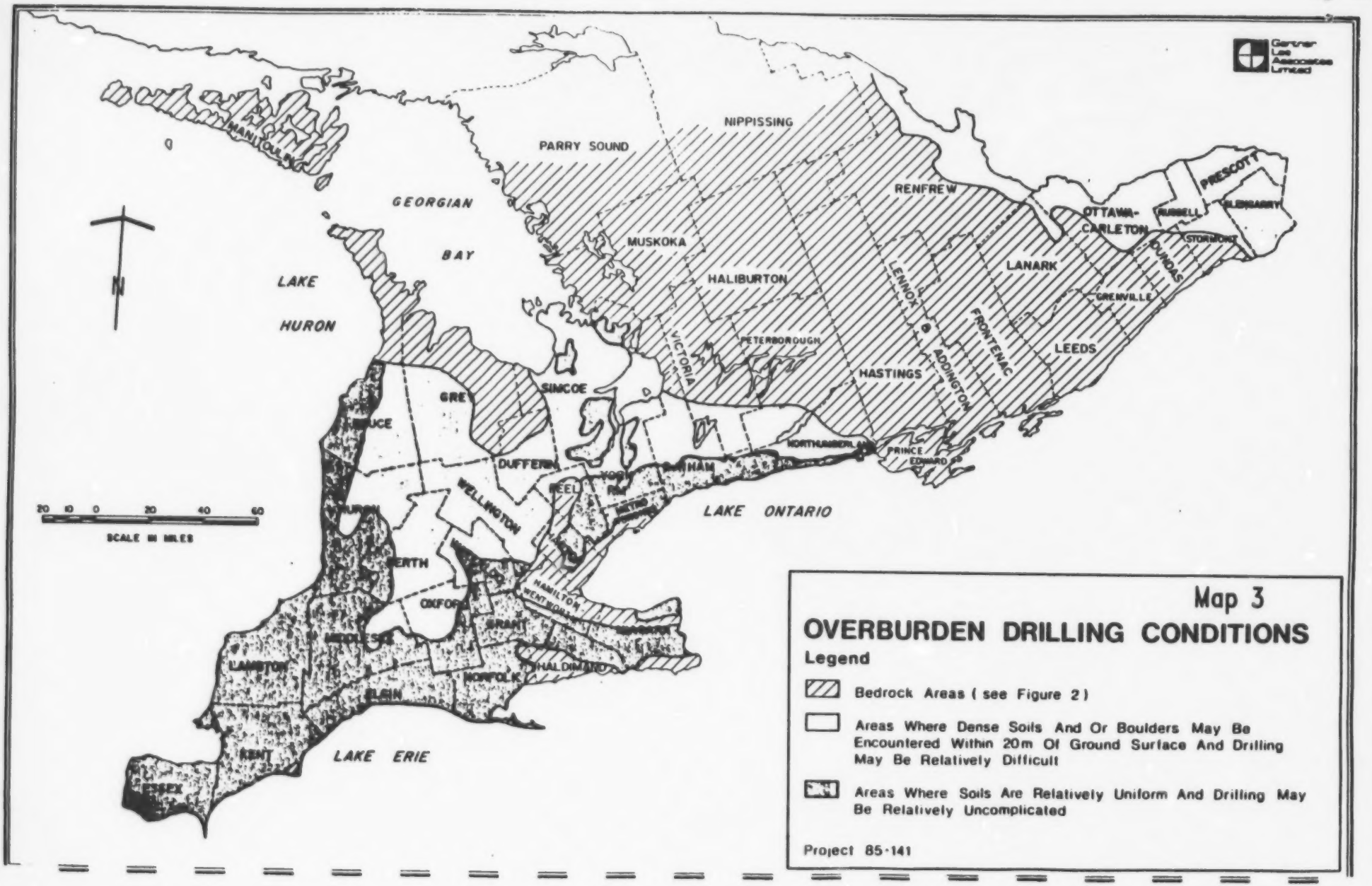

Map 3

OVERBURDEN DRILLING CONDITIONS

Legend

- Bedrock Areas (see Figure 2)
- Areas Where Dense Soils And Or Boulders May Be Encountered Within 20m Of Ground Surface And Drilling May Be Relatively Difficult
- Areas Where Soils Are Relatively Uniform And Drilling May Be Relatively Uncomplicated

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